SOCIAL-ECOLOGICAL SOUNDSCAPES: EXAMINING AIRCRAFT-HARVESTER-CARIBOU CONFLICT IN ARCTIC ALASKA

By

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Abstract

As human development expands across the Arctic, it is crucial to carefully assess the impacts to remote natural ecosystems and to indigenous communities that rely on wild resources for nutritional and cultural wellbeing. Because indigenous communities and wildlife populations are interdependent, assessing how human activities impact traditional harvest practices can advance our understanding of the human dimensions of wildlife management.

Indigenous communities across Arctic Alaska have expressed concern over the last four decades that low-flying aircraft interfere with their traditional harvest practices. For example, communities often have testified that aircraft disturb caribou (*Rangifer tarandus)* and thereby reduce harvest opportunities. Despite this longstanding concern, little research exists on the extent of aircraft activity in Arctic Alaska and on how aircraft affect the behavior and perceptions of harvesters. Therefore, the overarching goal of my research was to highlight the importance of aircraft-harvester conflict in Arctic Alaska and begin to address the issue using a scientific and community-driven approach.

In Chapter 1, I demonstrated that conflict between aircraft and indigenous harvesters in Arctic Alaska is a widespread, understudied, and complex issue. By conducting a meta-analysis of the available literature, I quantified the deficiency of scientific knowledge about the impacts of aircraft on rural communities and traditional harvest practices in the Arctic. My results indicated that no peer-reviewed literature has addressed the conflict between low-flying aircraft and traditional harvesters in Arctic Alaska. I speculated that the scale over which aircraft, rural communities, and wildlife interact limits scientists' ability to determine causal relationships and therefore detracts from their interest in researching the human dimension of this social-ecological system. Innovative research approaches like soundscape ecology could begin to quantify interactions and provide baseline data that may foster mitigation discourses among stakeholders.

In Chapter 2, I employed a soundscape-ecology approach to address concerns about aircraft activity expressed by the Alaska Native community of Nuiqsut. Nuiqsut faces the greatest volume of aircraft activity of any community in Arctic Alaska because of its proximity to intensive oil and gas activity. However, information on when and where these aircraft are flying is unavailable to residents, managers, and researchers. I worked closely with Nuiqsut residents to deploy acoustic monitoring systems along important caribou harvest corridors during the peak of caribou harvest, from early June through late August 2016. This method successfully captured aircraft sound and the community embraced my science for addressing local priorities. I found aircraft activity levels near Nuiqsut and surrounding oil developments (12 daily events) to be approximately six times greater than in areas over 30 km from the village (two daily events). Aircraft sound disturbance was 26 times lower in undeveloped areas (Noise Free Interval =13 hrs) than near human development (NFI = 0.5 hrs). My study provided baseline data on aircraft activity and noise levels. My research could be used by stakeholders and managers to develop conflict avoidance agreements and minimize interference with traditional harvest practices. Soundscape methods could be adapted to rural regions across Alaska that may be experiencing conflict with aircraft or other sources of noise that disrupt human-wildlife interactions.

By quantifying aircraft activity using a soundscape approach, I demonstrated a novel application of an emerging field in ecology and provided the first scientific data on one dimension of a larger social-ecological system. Future soundscape studies should be integrated with research on both harvester and caribou behaviors to understand how the components within this system are interacting over space and time. Understanding the long-term impacts to traditional harvest practices will require integrated, cross-disciplinary efforts that collaborate with communities and other relevant stakeholders. Finally, my research will likely spark efforts to monitor and mitigate aircraft impacts to wildlife populations and traditional harvest practices across Alaska, helping to inform a decision-making process currently hindered by an absence of objective data.

Table of Contents

Page

List of Figures

List of Tables

Page

List of Appendices

Page

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Introduction

Remote indigenous communities in Arctic Alaska have experienced an expansion of industrial activities, military operations, scientific research, and commerce over the last half-century. Aircraft accompanied this proliferation into the Arctic and, in the absence of a road system, became the primary means of transporting resources and people among Arctic developments (Decker and Kinney, 2013; Alaska Humanities Forum, 2016). Once-isolated communities now became connected to each other, to the rest of Alaska, and to rapidly changing socio-economic forces.

Although aircraft support many services and opportunities that benefit Alaska Native communities, indigenous residents expressed growing frustration with aircraft that fly over their traditional lands and disrupt their traditional harvest practices (USDOI BLM SAP, 2010, 2012-2014, 2016; SRB&A, 2013-2017; ICAS, 2014; National Petroleum Reserve in Alaska Working Group, 2014; NSB, 2016). Thus, an issue of human dimensions of wildlife management (Decker et al., 2012) has developed where human-human conflict related to wildlife has escalated. Frustration with low-flying and non-local aircraft has been documented for decades in public testimony, government reports, graduate theses, and social studies by private research groups (USDOI MMS, 1979; USAED, 1996; SRB&A 2009; USDOI BLM SAP, 2012-2014; Halas, 2015; Kunaknana, 2016; SRB&A, 2017). However, only recently have federal land managers issued conflict-avoidance agreements for aircraft users operating within their jurisdiction (USDOI BLM, 2017). The objectives of this study were to assess the urgency of aircraft-harvester conflict in Arctic Alaska and begin to address the issue using a scientific and community-driven approach.

Alaska Native harvesters and elders tell us that aircraft disturb caribou (*Rangifer tarandus*) and reduce harvest opportunities (Cuomo et al., 2008; Halas, 2015). Empirical knowledge corroborates this traditional knowledge, demonstrating that aircraft flyovers can induce restlessness or escape responses in ungulates (McCourt et al., 1974; Frid, 2003; Pepper et al., 2003; Côté et al., 2013), including caribou (Calef et al., 1976; Maier et al., 1998). Some evidence has suggested that ungulates may habituate to aircraft (Bowles, 1995; Maier et al., 1998) or tolerate them during high-stress seasons (Murphy and Curatolo, 1987). Although determining the causal relationships between aircraft disturbance and caribou fitness requires more rigorous research conducted at large spatial and temporal scales (Vistnes and Nellemann, 2008), local and short-term effects on caribou may still exert negative impacts on harvest success for indigenous communities. Exploring the human dimension of this problem may provide insight into the ultimate influence of disturbance on wildlife.

The Alaska branch of the National Science Foundation's Established Program to Stimulate Competitive Research (NSF EPSCoR) funded biological, physical, and social research on the capacity of Alaskan communities to respond to social-ecological change (University of Alaska, 2017). Alaska EPSCoR prioritized research that engaged local communities and/or stakeholders throughout study development, execution, and final delivery. As part of Alaska EPSCoR's Northern Test Case, the present study was driven by the concerns of the Native Village of Nuiqsut, an Alaska Native community in the high Arctic. I worked closely with Nuiqsut residents and tribal entities to design my study, implement my research, and interpret my findings. By doing so, my research advanced science while also remaining relevant to Nuiqsut's concerns.

My research sought to answer the question, "What is the extent of aircraft disturbance over Nuiqsut's traditional lands and where does it pose the greatest threat to harvest practices?" Described in the following chapters, my work highlighted the importance of this issue to residents and harvesters in Arctic Alaska, demonstrated the paucity of scientific data on aircraft-harvester interactions, and presented an effective approach to empirically investigate this understudied issue. I concluded by recommending ways to expand upon my research so that we may better understand interactions among aircraft, humans, and wildlife in the Arctic.

In Chapter 1, my objective was to quantify the extent of research on aircraft-harvester conflict in the Arctic. I surveyed current scientific knowledge on the impacts of aircraft to humans and wildlife by conducting a systematic search of the literature using Google Scholar. I analyzed what proportions of available literature represent research on aircraft-wildlife interactions in general, aircraft-human relations in urban areas, and aircraft-harvester conflict in the Arctic. I then provided important context about why aircraft constitutes a disturbance to Alaska Native harvesters, and I presented opportunities for researchers, managers, and stakeholders to address this conflict.

In Chapter 2, I demonstrated a novel application of soundscape ecology to quantify aircraft disturbance over Nuiqsut's traditional harvest lands. Soundscape ecology (Ambrose and Burson, 2004; Pijanowski et al., 2011; Fristrup and Mennitt, 2012; Merchant et al., 2015) offers innovative methods to scientifically quantify human disturbance in remote regions. By deploying devices that record continuous environmental sound, soundscape ecologists can examine the distribution of sounds in a landscape and how this distribution influences social-ecological systems. By analyzing the proportional audibility of natural sounds (e.g., wind, water, thunder), biological sounds (e.g., wildlife calls), and anthropogenic sounds (e.g., vehicles, industrial noise, human voices), soundscape ecologists can infer the characteristics of local environments and assess how environments change over space and time.

Since 2000, the National Park Service (NPS) developed and deployed acoustic monitoring devices to inventory soundscapes across the USA (Lynch et al., 2011; Betchkal, 2013, 2015). Although Arctic Alaska does not contain a national park, NPS research can be easily modified for remote landscapes and villages like Nuiqsut. Here, I drew from NPS methods and technology to deploy 20 acoustic monitoring devices along Nuiqsut's traditional harvest corridors from June through late August 2016. I used aircraft activity rates and noise metrics to characterize overall disturbance levels across the study area. My study provided baseline data on aircraft activity and noise levels during the peak harvest season. My dataset can be used for future research beyond the goals of this study, including biodiversity analyses, environmental impact assessments, or avian distributional studies. For example, in addition to quantifying aircraft disturbance, my dataset can be used to quantify baseline data for the natural environment, catalog bird species on the North Slope, and expand current models of sound levels across Alaska.

With this work, I examined the state of knowledge on aircraft-human-wildlife interactions in the Arctic and quantified the gap in knowledge on aircraft-harvester conflict. I advanced the emerging field of soundscape ecology by testing its methods in the Arctic and demonstrating that it can be an effective tool for addressing questions that concern the human dimensions of wildlife management. I also advanced the conversation about traditional harvest practices and the economic and sociocultural significance that they carry for indigenous communities around the globe (Brashares et al., 2004; Wilkie and Carpenter, 1999). Finally, this work can contribute to interdisciplinary efforts that address how changes in local anthropogenic landscapes influence the dynamics of social-ecological systems.

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Chapter 1: Assessing the urgency to research aircraft-harvester conflict in Arctic Alaska[1]

1.1 Abstract

The traditional harvest of wild resources, also known as subsistence, carries significant provisional, economic, and sociocultural values for indigenous people of Alaska. Alaska Native communities in the Arctic contest that aircraft activity from industry, commercial hunting, research, and tourism disrupts their harvest of wildlife, particularly caribou (*Rangifer tarandus*). As aircraft operations for commerce and development increase across the Arctic, any interference with traditional harvest practices could threaten the wellbeing and cultural integrity of Alaska Native communities. However, little research exists on how aircraft affects the behavior of harvesters and caribou, and consequently impacts harvest opportunities. Our objective was to assess the extent of scientific knowledge on aircraft-harvester interaction in the Arctic. We conducted a systematic search of the available literature and found that not one peer-reviewed publication addressed the conflict between aircraft and indigenous harvesters. Therefore, we drew from research on perceptions of aircraft in gray literature to understand why aircraft constitutes a disturbance to the Alaska Native harvester. Harvester frustration may be directed toward low-flying and non-local operations that compete for local land use and resources (e.g., oil and gas development and sport-hunting). Mitigating aircraft-harvester conflict will require better cooperation among communities, researchers, land users, and decision-makers. We recommend that aircraft operators develop conflict avoidance agreements and communicate with the local community. Future research should be community-driven and produce tools for stakeholders to engage in mitigation discourses. Soundscape ecology offers

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[1] Stinchcomb, T.R., Brinkman, T.J., and Fritz, S.A. Assessing the urgency to research aircraft-harvester conflict in Arctic Alaska. Prepared for submission to *Arctic*.

one such approach to begin quantifying the interactions among aircraft, harvesters, and wildlife in Arctic Alaska.

1.2 Introduction

Low-flying aircraft traffic is a pressing concern for Alaska Native communities across Arctic Alaska. Community members contest that aircraft disturb wildlife and their traditional harvest success (USDOI BLM SAP, 2010, 2012-2014, 2016; SRB&A, 2013-2016; ICAS, 2014; National Petroleum Reserve in Alaska Working Group, 2014; NSB, 2016). The harvest of Arctic wildlife including terrestrial and marine mammals provides Alaska Native communities with direct nutritional and economic benefits (Nuttall, 2000). Traditional harvest practices also underlay social relationships, networks of sharing, and cultural identity (BurnSilver et al., 2016; Fall, 2016). Disruption of traditional harvests could undermine community wellbeing and sociocultural integrity (Lambden et al., 2007; Smith et al., 2009; Loring and Gerlach, 2015).

The conflict between Alaska Native communities and aircraft has been documented for decades in public hearings on proposed developments (USDOI MMS, 1979; USAED, 1996; USDOI BLM, 1997, 2003) and proceedings of the Bureau of Land Management National Petroleum Reserve-Alaska Subsistence Advisory Panel (USDOI BLM SAP, 2010, 2012-2014, 2016; SRB&A, 2009), but the issue remains difficult to solve using contemporary management and monitoring programs (USDOI BLM, 2017). Meanwhile, aircraft traffic continues to increase over Arctic Alaska to support transit of Arctic residents, oil and gas development, scientific research, tourism, and commercial hunting opportunities (Carr et al., 2013; Osipov et al., 2016). To our knowledge, few efforts have sought to determine the impact of aircraft activity on traditional harvest practices and the consequent implications for community wellbeing and resilience. Aircraft traffic and commerce across the Arctic may continue to impact Alaska Native culture unless researchers introduce new approaches to understand aircraft-harvester interactions and stakeholders engage in cooperative management agreements.

To address this understudied and important topic, we aimed to (i) quantify the extent of scientific knowledge on aircraft-harvester interactions in the Arctic by conducting a systematic search of the available literature; (ii) understand the relationship between aircraft and Alaska Native harvesters by reviewing the available peer-reviewed and gray literature; (iii) outline the complexities of this issue; and (iv) propose opportunities for management and experimental research to address the concerns of Alaska Native communities.

This paper will contribute to Arctic scholarship by demonstrating the deficiency of peer-reviewed scientific research on the interactions between aircraft activity and traditional harvest practices. We focus on perceptions of aircraft by Alaska Native harvesters because the direct interaction between traditional harvesters and aircraft is the least studied component of this system, and traditional knowledge across northern Alaska tells us that harvesters are responding to aircraft activity in ways that could compromise their harvest success. Ultimately, we seek to advance the conversations about (i) the complex relationship between aircraft users and traditional harvesters in remote Arctic regions; and (ii) how scientific research could begin to address the concerns of Native communities.

1.3 Study Area

Our assessment of the interactions between aircraft traffic and traditional harvest opportunities focused on the North Slope of Alaska. The North Slope comprises an area of 245,520 km^2 that spans from the northern edge of the Brooks Range to Alaska's coastline along the Arctic Ocean and the Beaufort and Chukchi Seas (Fig. 1-1). Flat tundra covered by sedges, low-lying shrubs, and lichens provides habitat for wide-ranging terrestrial mammals like caribou, moose (*Alces alces*), grizzly bear (*Ursus arctos*), wolf (*Canis lupus*), and fox (*Vulpes vulpes, V. lagopus*). During the summer (June-September), the tundra is broken by a patchwork of lakes, marshes, and waterways that open breeding grounds for waterfowl and spawning habitat for many anadromous and freshwater fish species (e.g., *Salvelinus spp., Coregonus spp.*). During the winter, the landscape remains frozen and snow-covered, and winds can drop temperatures below -59 °C.

This North Slope is also home to eight communities of Alaska Native people who rely on seasonal harvests of fish, wildlife, and flora for nutrition and survival through the severe Arctic winters. The customary and traditional use of wild resources for nutritional and consumptive purposes (e.g., food, shelter, fuel, clothing, tools, transportation, trade, barter, and sharing) is classified as subsistence under state and federal law (Alaska Statute 16.05.258; Alaska National Interest Lands Conservation Act; Public Law 96-487, Title VIII). Subsistence, as understood by Alaska Native peoples, comprises a direct relationship with the environment that transects ecological, economic, and sociocultural spheres (Wolfe, 1984; Nuttall et al., 2004; Halas, 2015). It forms the foundation of social relationships, cooperative networks of sharing, and cultural identity (Galginaitis and Petterson, 1990; Nuttall et al., 2004; Bacon et al., 2011; Alaska Federation of Natives, 2012; Berkes, 2012; Brubaker et al., 2014). Some communities perceive the term *subsistence* as reductionist and politicized, and prefer the phrases *traditional way of life* or *traditional harvest practices* to describe their hunting, fishing, gathering, and trapping practices. Therefore, we use *traditional harvest practices* to encompass the common understanding of subsistence and account for local concerns.

The influx of industry into Alaska's North Slope during the 20th century brought both new opportunities and new conflicts for local Alaska Native communities. Prior to WWII, most communities had limited contact with Western society, technologies, or economies. Military-industrial expansion during WWII and the Cold War era established aircraft operators in Arctic Alaska to support military defenses and industrial development. Commercial oil production at Prudhoe Bay (Fig. 1-1) in 1968 expanded capitalist markets formerly established for the fur trade in Alaska Native communities. Tax revenues from oil development across the North Slope funded local community improvements including clinics, schools, sewage systems, fire stations, and local airports (Kruse et al., 1982; URS Corporation, 2005). Oil companies offered wage-based occupations for Alaska Native men that supplemented traditional livelihoods (Brower, 1980). As steady work restricted the time available to engage in traditional harvest, processed foods imported by aircraft and purchased at the local store offered alternatives to wild resources. Industrial production transformed rural hunter-gatherer economies into mixed subsistence-cash economies. Village residents simultaneously engaged in commercial markets and wage employment while maintaining traditional harvest practices and social networks for distributing their harvest (Wolfe, 1984; BurnSilver et al., 2016; Magdanz et al., 2016).

Lying at the convergence of four on-shore state and federal oil and gas tracts, the Alaska Native village of Nuiqsut (70.2175° N, 150.9764° W, Fig. 1-2) is quickly becoming surrounded by industrial operations (USDOI BLM, 2003; Ahtuangaurak, 2015) and experiencing more concentrated impacts from aircraft than any other North Slope community (NSB, 2015). Nuiqsut is a village with 411 residents (US Census Bureau, 2016) located approximately 29 km inland from the Arctic Ocean along the western bank of the Colville River delta. The Colville River flows north from the Brooks Range (Fig. 1-1) and serves as the principal corridor by which Nuiqsut residents travel to pursue fish and wildlife resources (Braem et al., 2011; SRB&A, 2014). Terrestrial mammals make up just under 30% of Nuiqsut's annual traditional harvest, and caribou comprise 22-28% of total usable harvest weight per capita (George and Fuller, 1997; URS Corporation, 2005; Brown et al., 2016). Caribou thus represent the most important terrestrial species for Nuiqsut residents (Brower and Hepa, 1998). Traditional harvest areas for caribou extend west of the community into the NPR-A, and east of the community around the Colville delta and the Itkillik River (SRB&A, 2016). Nuiqsut residents harvest caribou year-round, but the peak harvest season occurs in the summer aligning with the peak season for aircraft associated with oil and gas operations

Oil industry expansion is affecting traditional harvest practices by shifting traditional use areas away from well pads, pipelines, and roads (National Research Council, 2003; Pedersen, et al., 2009; SRB&A, 2009, 2013-2017) and may be shifting the distribution of wild game on which traditional harvesters rely (Wilson et al., 2016). As construction commenced on oil infrastructure just 13 km northeast of Nuiqsut from 2005 to 2014, harvest declined from previous years along the Colville River delta where industrial traffic was concentrated (SRB&A, 2014). Similar shifts have been documented during expansion of oilfields on the eastern side of the Colville River (Fig.1-2). Many harvesters now avoid this area (Galginaitis and Petterson, 1990; SRB&A, 2016).

Nuiqsut residents have expressed concern that oil developments are encroaching on hunting and fishing camps, and that the associated aircraft activity is impeding their access to traditional resources, especially caribou (USDOI BLM, 2003). One third (32%) of Nuiqsut harvesters surveyed in 2015 reported that helicopter traffic affects their caribou harvest (SRB&A, 2016). Helicopter interference accounted for over half of all reported impacts to traditional harvest activities in the following year (SRB&A, 2017). Encounters with aircraft detract from the aesthetic quality and cultural connection that many Native people expect to experience while harvesting traditional resources (Cuomo et al., 2008; Halas, 2015). As a result, harvesters tend to avoid regions of dense human activity where aircraft are likely to fly (Galginaitis and Petterson, 1990; Kunaknana, 2016; SRB&A, 2016). Harvester avoidance reduces harvest opportunities and increases costs to travel farther for longer periods of time (Kruse et al., 1982; National Research Council, 2003; Nuttall et al., 2004; Hansen et al., 2013; NSB, 2014). However, the unpredictability and ubiquity of flight paths likely elevates harvester frustration with aircraft activity (Hatfield et al., 2002). Unlike aircraft, static features such as roads, pipelines, and well pads can be actively avoided by harvesters.

Aircraft interference with harvest practices is not a recent issue for North Slope communities. Brown (1979) included aircraft in the “onslaught” (38) of forces and strangers that were intruding on Nuiqsut, altering the environment, and disrupting traditional harvest practices. Efforts to document subsistence harvest statistics for Nuiqsut in the late 1990s recorded harvester observations that aircraft fly over traditional lands and harass caribou (Brower and Hepa, 1998). In 2007, active harvesters from Nuiqsut, Utqiaġvik (formerly Barrow), Atqasuk, and Wainwright cited the displacement of wildlife by industry activity and aircraft as the number one impact to their communities from oil and gas development (SRB&A, 2009). Interviewed harvesters reported that noise related to oil and gas operations (e.g., seismic exploration, boats or barges, and helicopters) has disrupted marine and terrestrial wildlife since the late 1970s. Specific reports about aircraft activity changing caribou migration routes and frustrating harvesters have been increasing since the early 2000s (SRB&A, 2009). Nuiqsut harvesters expressed concerns with aircraft annually over the last decade (SRB&A, 2009, 2013-2017), but social surveys only recently included questions explicitly about harvester avoidance of historic harvest areas (SRB&A, 2016-2017).

Despite the concern and consequences associated with aircraft-harvester interactions, no existing literature synthesizes current knowledge about how aircraft activity impacts traditional harvest practices. Here, we conduct a systematic search of the available literature on aircraft disturbance in the Arctic and aircraft conflict with Alaska Native communities. We then review why aircraft traffic constitutes a disturbance to the Alaska Native harvester and what opportunities exist for researching and managing its impacts on traditional harvest practices.

1.4 Systematic Search Methods

To determine the degree to which aircraft conflict was assessed by peer-reviewed literature, we conducted a series of four searches on Google Scholar using combinations of four to six keywords: “aircraft noise” or “aircraft disturbance,” “wildlife” or “humans,” “Arctic” or “Alaska,” and “annoyance” or “behavior.” The four search strings were:

1. aircraft disturbance subsistence Arctic OR Alaska
2. aircraft noise wildlife Arctic OR Alaska
3. aircraft noise humans Arctic annoyance rural OR subsistence
4. aircraft noise humans annoyance OR behavior

The purpose of the fourth search was to compare the literature on human-aircraft relations in urban environments to that in rural or subsistence communities; we thus did not limit this search to the Arctic region.

For each search, we mined through the first ten pages of results with 20 items per page. This represents a total of 800 articles examined across the four searches. We saved relevant articles to My Library on Google Scholar and tagged them with the corresponding search string. An article was deemed relevant if it specifically discussed wildlife/human responses to aircraft, or aircraft in relation to industrial development or traffic noise.

We chose to include articles concerning soundscape features and changes in soundscapes, because these tend to discuss the influence of motorized noise on wildlife behavior or human perceptions of nature (see Krause, 1999; Hults and Burson, 2006; Barber et al., 2009; Dumyahn and Pijanowski, 2011; Brown et al., 2012 in Appendix 1A). We excluded results that contained one or more of the keywords only in a citation rather than the main text. We chose to include gray literature in our selection of relevant results because it could serve as a practical measure of knowledge on the issue as compared to peer-reviewed studies. By our definition, gray literature includes articles which are not published in a peer-reviewed journal. For example, our search generated government agency reports, theses and dissertations, environmental impact statements, news or magazine articles, and reports from non-governmental organizations like the National Resources Defense Council (NRDC) or the North Slope Borough (NSB) or from tribal consortia like the Inupiat Community of the Arctic Slope (ICAS). We hypothesize that gray literature will comprise most available sources on aircraft-harvester conflict.

After completing all four searches, we coded each saved article with one of three categories: impacts to wildlife (WLF), impacts to human-wildlife interactions (HUM-WLF), or impacts on human communities unrelated to wildlife (human-non-wildlife or HUM-NW). We then generated sub-categories to identify the primary topic or question that each article addressed and how it related to aircraft. We determined the proportion of results in each sub-category and then compared proportions within and among our three main categories. We provide a complete list of the literature results from our searches in Appendix 1A.

1.5 Results

Of the 800 articles that we examined on Google Scholar, 101 (12.6%) were related explicitly to the effects of aircraft on humans and/or wildlife. Aircraft-specific impacts on human communities in urban or developed environments outside of the Arctic were the subject of 53 of these articles (52.5%) while 23 (22.8%) dealt with the Arctic or Alaska. Another 100 (12.5%) mentioned aircraft impacts in association with motorized noise or industrial activities, 24 of which dealt with the Arctic or Alaska. The impacts of noise in general were discussed in 22 (2.8%) results. This gave us a total of 220 articles that were relevant to our analysis (27.5% of search results).

Twenty-eight articles turned up on two or more search strings, 13 of which (46.4%) reviewed the responses of wildlife to human disturbances, including aircraft activity (Appendix 1A). Other topics that came up during our searches include: general anthropogenic disturbance to wildlife; the status of traditionally harvested species (e.g., *Branta bernicla nigricans*, *Somateria mollissima*, *Balaena mysticetus*, and *Thymallus arcticus*); the efficacy of aerial surveys; economic development in the Arctic; the policy of of wildlife harvest; wildlife strikes to civil aircraft; the use of Unmanned Aircraft Systems; and the impacts of environmental noise on developed environments.

Over half (*n* = 111, 50.5%) of the relevant articles addressed the impacts of aircraft and other noise on wildlife rather than on human communities (Fig. 1-3). Although we searched for literature exclusively about the Arctic or Alaska, we found 31 articles on non-Arctic species. Aircraft was typically mentioned in association with shipping or industrial activity. Of the 42 articles relevant to Arctic species, 47.6% regarded marine species and the effects of shipping noise or offshore oil development. Caribou were either the primary subject of the article or mentioned in association with other ungulates in 31.7% of literature on Arctic wildlife. The remaining results consisted of literature reviews and government documents, such as Environmental Impact Statements, on the effects of human-derived disturbance on wildlife.

Human-non-wildlife (HUM-NW) comprised 41% (n = 91) of saved articles, all of which concerned urban or developed areas outside of the Arctic. One exception is a government report on the impacts of occupational noise to the health of farmers in rural British Columbia, Canada (see Winters et al., 2005 in Appendix 1A). Studies on the health of urban and suburban residents or the performance of schoolchildren near high-traffic airports dominated this category (n = 50, 54.3%). Annoyance as an emotional response to aircraft was the primary subject of 25% of HUM-NW articles. Only five articles (5.4% of HUM-NW) investigated how aircraft or other motorized noise affects human perceptions of natural landscapes or experiences within a national park.

Out of all search results, only ten (4.5%) concerned aircraft noise and traditional harvest practices in some capacity (Fig. 1-3). All but two were published in the last 16 years. The majority (60%) of HUM-WLF articles fall into our definition of gray literature including government reports, theses or dissertations, press releases, and open letters by tribal organizations. Aircraft impacts on traditional harvest practices tended to be mentioned briefly in context with impacts to the migration of harvested species like caribou (see Fullman et al., 2017 in Appendix 1A) or bowhead whale (see Goodyear, 2012 in Appendix 1A). Only two out of all articles we examined discuss the conflict between traditional harvesters and aircraft users and/or industry from the perspective of Alaska Native culture. One of these is a graduate thesis (see Halas, 2015 in Appendix 1A) and the other is an editorial from a North Slope resident (see Ahtuangaruak, 2015 in Appendix 1A). Two interview-based studies from Canada discuss the role of traditional harvest practices in a mixed economy and conflicts among industry, tourism, and indigenous harvesters (see Dressler et al., 2001 and Dana et al., 2009 in Appendix 1A). Two agency reports (see Georgette and Loon, 1988, 1990 in Appendix 1A) discuss the conflict between aircraft and (i) caribou harvesters in Noatak, Alaska, and (ii) subsistence fishermen on the Kobuk River, Alaska. Despite these results from the gray literature, not a single peer-reviewed article on Google Scholar addressed the issue of aircraft disturbance to traditional harvest practices in the Arctic.

1.6 Discussion

Our analysis demonstrates that, incongruous with the level of concern expressed by Arctic residents, a severe deficiency exists in the peer-reviewed literature regarding the sociocultural consequences of aircraft disturbance to rural Arctic communities. Changes in the land use and behavior of harvesters themselves (e.g., harvester avoidance of high-traffic areas) have not been studied and reported in peer-reviewed outlets by the scientific community. The complex and variable interactions among harvester behavior, wildlife movements, and aircraft activity levels make it extremely difficult for scientists to disentangle cause-and-effect relationships. We speculate that coordinated and collaborative research efforts are needed to understand how traditional harvest practices will be directly impacted by increasing aircraft traffic at northern latitudes.

Historical records, ethnographies, government reports, and public testimonies currently contain the most information about aircraft-harvester conflict in Arctic Alaska. In the following sections, we rely heavily on this body of gray literature to draw inferences about the behavior of traditional harvesters and their attitudes toward aircraft. We examine why aircraft traffic constitutes a disturbance to Alaska Native harvesters and explore what opportunities exist for managing the impacts of aircraft on traditional hunting practices.

1.6.1 Noise Disturbance and Human Perception

Noise is defined as any unwanted, undesired, or unpleasant sound (Merriam-Webster, 2017) that interferes with a person’s physical, emotional, and/or cognitive state (Pepper et al., 2003). Sound levels perceived as unwanted or annoying by humans (40-100 dBA at a reference air pressure of 20 µPa) correspond with the range of sound levels emitted by low-flying aircraft (Shannon et al., 2015). Aircraft sound is concentrated at low frequencies (20-250 Hz), which lose little energy over long distances and produce vibrations that regularly elicit feelings of discomfort and annoyance (Berglund and Hassmen, 1996).

National park visitors react negatively toward seeing and hearing aircraft in natural or wilderness areas and consider helicopters the most annoying even at relatively low levels (40 dBA, Mace et al., 1999; Bell et al., 2010). The sight of an aircraft degrades visitors’ perceptions of a pristine landscape and the natural character of the landscape diminishes as aircraft occurrences or noise levels increase. Seclusion contributes strongly to the satisfaction of sport and traditional harvesters from across the U.S (Heberlein, 2002; Vaske and Shelby, 2008). Many Alaska Native people share the expectation for a peaceful experience while harvesting traditional resources (Kaigelak, 2014; USDOI BLM SAP, 2014). Aircraft noise is a product of recent development and population growth around Alaska Native communities and is understood as disturbance to the natural environment. Intermittent and unpredictable aircraft overflights invade the traditional harvest experience, disrupting this vital economic and cultural activity. As Mace et al. (1999) describe, sounds “perceived as avoidable and abnormal to the situation” are more likely to cause annoyance (226). Alaska Native harvesters may feel disturbed that they have little control over flight times and trajectories, augmenting their general frustration toward aircraft (Hatfield et al., 2002).

1.6.2 Aircraft-Harvester Interactions

The relationship between aircraft and Alaska Native communities is a double-edged sword. Modern hunting requires cash income for fuel, equipment, and ammunition (Brown, 1979; Nuttall et al., 2004; Brinkman et al., 2014), but the cash flow to North Slope communities depends heavily on oil development and the associated use of aircraft. Small aircraft also provide the main mode of transporting local people and supplies to and from the community. Regularly scheduled aircraft traffic is needed for commerce and safety.

Frustration with aircraft may stem from the perceived intrusion of non-local operations into daily activities and traditional harvest practices of local people. Although North Slope residents regularly use motorized vehicles like boats, all-terrain vehicles, and snowmobiles for harvest and recreational activities, it is unlikely that these vehicles disturb the typical harvester. Arguably, boats and overland vehicles aid in harvest success by allowing the harvester to travel greater distances and carry larger loads when their time is constrained by employment obligations or harvest seasons (Brinkman et al., 2014). Native harvesters are mainly concerned with aircraft noise because it takes away harvest opportunities that are becoming increasingly limited by economic costs and ecological changes.

We speculate that outside aircraft sources that compete directly with harvesters for local resources might generate an additional level of frustration for local communities. Nonresident sport hunters hire private pilots to transport them around the North Slope, allured by world-class hunting opportunities for Arctic wildlife including moose, caribou, Dall sheep (*Ovis dalli dalli*) and grizzly bear. Commercial hunting constitutes a significant sector of Alaska's economy. For example, guided hunters contribute on average 39% of annual nonresident hunting revenue to the state from license and tag fees (McDowell Group 2014, 2017). However, conflict between sport-hunting aircraft and Alaska Native harvesters is widespread across Interior and Arctic Alaska (Halas, 2015). Native harvesters contend that sport hunters transported by bush planes harass the caribou and divert them from traditional migration routes (Steinacher, 2006; US Army Corps of Engineers, 2016). Residents of Anaktuvuk Pass in the Brooks Range blame sport hunters and the aircraft that carry them for changing caribou routes away from the pass. As an interior community without access to marine resources, they rely on the annual caribou migration for most of their harvested food supply (USDOI BLM SAP 2010, 2016).

Much of the research conducted to understand changes in the local resources on which residents rely requires the use of aircraft. Nuiqsut has been the subject of extensive scientific and anthropological research efforts since the early 1970s (Kruse et al., 1982). Private entities under contract with oil companies conduct research on environmental impacts, traditional harvest statistics, and social attitudes toward development. Extensive research has been conducted on the biology of North Slope caribou by both public entities (Skoog, 1968; Davis et al., 1980; Klein, 1991a; Klein, 1991b; Bergerud, 1996; Valkenburg, 2001; Cameron et al., 2005; Carroll et al., 2005) and privately contracted companies (Wilson et al., 2012). The research fatigue felt by Nuiqsut residents exacerbates their frustration with aircraft that transport researchers among villages and field sites.

The continued use of aircraft by researchers increases traffic in and around North Slope communities, running counter to many research groups' goals for environmental impact mitigation and cultural preservation. Several community members recommend using satellite imagery to reduce the number of air-based wildlife surveys during the harvest season and minimize conflict with caribou harvesters (USDOI BLM SAP, 2016). Yet many agencies do not have the funds to invest in remote-sensing technologies, nor the technical capacity to process those data in a way that could reduce their dependence on aircraft for wildlife surveys (Carroll, 2012). Recruiting local harvesters to record wildlife sightings or hiring local guides to travel by boat or all-terrain vehicle could simultaneously reduce the number of required flights and foster greater community investment in scientific research. For researchers, however, access to remote field sites or wide-ranging wildlife populations is extremely difficult without a helicopter or small aircraft. Completely prohibiting transportation by aircraft would constrain scientists' ability to access much of the North Slope's isolated environment and research pressing issues such as coastal erosion, hydrological change (Brown, 1979), and climate change adaptation (Hinzman et al., 2005).

Regardless of the purpose of an aircraft, a flight over caribou or over the harvester can affect that harvest opportunity. High-traffic areas can also reduce the quality of a harvest experience in that patch of landscape. Over half (58%) of Nuiqsut harvesters report avoiding traditional lands due to heightened motorized activity, infrastructure development, or safety concerns (SRB&A, 2016). As harvesters abandon traditional areas, they not only lose those harvest opportunities, but they lose a central piece of their cultural identity (Galginaitis and Petterson, 1990; Nuttall et al., 2004; Cuomo et al., 2008; Ahtuangaruak, 2015; Nukapigak and Kuukpik Corporation, 2016). The place names and the oral history behind them are no longer passed on to the next generation (USDOI BLM, 2003). Such threat of cultural loss contributes to perceptions of aircraft as invasive to the traditional way of life (Cuomo et al., 2008).

1.6.3 Opportunities for Research and Management

No studies to date have sought to examine the overlap among industrial and aircraft activity, traditional harvest patterns, and traditional resources such as caribou in Arctic Alaska. This knowledge gap limits our ability to assess the causes and consequences of conflict between aircraft users and Alaska Native people. Aircraft traffic is difficult to monitor, document, and regulate, particularly when it comprises such diverse users as it does on Alaska's North Slope. Aircraft may be flying over traditional harvest areas during peak harvest seasons, but inconsistent reporting from various aircraft operators and a lack of publicly accessible records impede the dissemination of flight path data. Even if pilots are willing to consistently log their flight tracks, substantial human capital would be required for an entity (e.g., government agency, research group, or nongovernmental organization) to compile, organize, and distribute this information to interested parties or to manage an open-access database. Pilots are not at fault in this issue; it involves a multitude of players acting over an expansive region, each with behaviors that we expect to vary widely over space and time. All players involved are, to the best of our knowledge, following the current rules, but those rules and regulations appear inadequate to address the concerns of Alaska Native harvesters.

Flight restrictions exist to minimize aircraft impacts to subsistence harvests across federal, state, and local levels, but these standards remain inconsistent. For instance, small aircraft and helicopters are restricted to a minimum altitude of 305 m over caribou herds by the Bureau of Land Management (BLM) or to 457 m by State of Alaska and North Slope Borough regulations (NSB, 2014). Repeated requests from harvesters and community leaders for aircraft to fly higher (Napageak, 2000; Brower, 2003) suggest that pilots are either not following these restrictions or that the minimum altitude is too low to be socially acceptable. Pilots often need to fly below minimum altitude during low visibility or hazardous conditions. Various government agencies recommend altering flight timing or trajectories and even avoiding use of aircraft altogether when possible, especially over "known subsistence camps and cabins or during sensitive subsistence harvest periods" (USDOI BLM, 2013:66). Although these regulations mention a potential conflict with traditional harvest practices, to our knowledge only the BLM delineates critical-use areas that aircraft should avoid (e.g., locations of camps and cabins or travel corridors), or seasons of peak caribou harvest when air traffic should be restricted (e.g., late May-late August, USDOI BLM, 2013). Yet federal authority does not extend beyond the NPR-A (Fig. 1-1), and the number of flights subject to BLM restrictions represents a small proportion of overall aircraft activity on the North Slope (USDOI BLM, 2017).

Local communities argue that enforcement of regulations is lacking and that flight records are not accessible to residents and tribal entities, curbing their capacity to engage in a management discourse (USDOI BLM SAP, 2012; Akpik-Lemen, 2015). Perhaps the most frequent recommendation during public hearings and advisory panel meetings is the need for communication between aircraft users and local communities. Community members need to be informed directly and regularly about when and where aircraft are occurring (Ahsogeak, 2014). They often request notification of scheduled flights and tracking information to improve transparency (Nukapigak, 2014). Developing communication plans with local communities is recommended across borough, state, and federal agency levels. Recent assessments of ongoing development in the NPR-A establish improved communication as a measure to mitigate the social impacts of industry activities (USDOI BLM, 2015). The BLM Aviation Awareness and Conflict Avoidance Agreement (USDOI BLM, 2017) requests permitted aircraft operators to avoid harvesters and caribou when possible, to land away from camps and active harvest areas, and to notify the local community government entities about flight activities. Conflict Avoidance Agreements between the Alaska Eskimo Whaling Commission and oil companies to halt activities during the traditional whaling season have proven successful for Nuiqsut and Kaktovik (Galginaitis and Petterson, 1990; Lefevre, 2013). Nuiqsut leaders identify such cooperative agreements as the most immediate strategy to protect the community's access to traditional resources (Brown, 1979). This might serve as the starting point for managing aircraft-harvester conflict in the region.

The emerging field of soundscape ecology (Ambrose and Burson, 2004; Pijanowski et al., 2011; Fristrup and Mennitt, 2012; Merchant et al., 2015) offers a fruitful opportunity to collaborate with Native communities and quantify aircraft disturbance over traditional harvest areas. By recording continuous environmental sound, acoustic monitoring systems can capture the composition of the local soundscape, and researchers can determine both the number of aircraft occurring and the level of noise they produce. In 2000, the Natural Sounds and Night Skies Division of the National Park Service began an acoustic monitoring program on public lands across the United States to document natural soundscapes and determine the degree of disturbance arising from human activities including aircraft noise (Lynch et al., 2011).

Similar methods could be applied to the North Slope where baseline data about aircraft traffic are lacking. Acoustic monitoring could work to circumvent the complicated, relatively intrusive, and labor-intensive effort of compiling flight logs from all aircraft users in the region. A series of soundscape studies collaborating with different North Slope communities could provide baseline information about where and when aircraft occur over traditional harvest areas and the level of noise they produce over different regions. The resulting soundscape profiles and maps of aircraft disturbance could serve as useful tools for local harvesters to engage with decision makers and develop conflict avoidance agreements with aircraft users. Much work remains to be done to foster this level of coordination among aircraft users, researchers, and Alaska Native communities.

1.7 Conclusion

Aircraft serve diverse purposes on Alaska's North Slope, some of which conflict with traditional harvest practices. Flights over traditional harvest areas during peak harvest seasons could reduce the harvest success for Alaska Native communities that rely on caribou and other wildlife for economic and cultural wellbeing. While the conflict between Alaska Native harvesters and aircraft is documented in public records, we found a deficiency in peer-reviewed research on aircraft-human relations in rural Arctic communities. No peer-reviewed studies to our knowledge address how traditional harvest areas have changed due to harvester avoidance of aircraft traffic. Scientific knowledge about aircraft in the Arctic mostly regards the impacts to marine and terrestrial wildlife. The effects of aircraft disturbance on caribou—the most important terrestrial resource for North Slope communities—are inconclusive. Changes in wildlife behavior or movement indirectly affect human communities that harvest them, but direct impacts of aircraft on traditional harvest practices have yet to be quantified.

These multifaceted, interacting variables complicate our ability to deconstruct cause-and-effect relationships between aircraft and traditional harvest practices. The spatial and temporal scales of published research are too narrow to disentangle the interactions among aircraft, harvesters, and caribou and the annual variability of these interactions. Experimental research at the scale needed to understand causal relationships would be extremely costly, and likely considered personally invasive by both traditional harvesters and aircraft pilots. Tackling this issue will require a coordinated effort among institutions with multidisciplinary expertise. Currently, only one ten-year study is underway to examine how the harvest patterns of Nuiqsut residents are changing over time, based on household surveys and harvester interviews (SRB&A, 2009, 2013-2017), and reviewed annually by a panel of local caribou harvesters. Reports from years seven (SRB&A, 2016) and eight (SRB&A, 2017) document several statements of aircraft activity, especially helicopters, influencing the avoidance of former harvest areas. These data have resulted in numerous mitigation measures designed to reduce conflict with aircraft, but the effectiveness of such measures faces several limitations:

(i) agencies have differential jurisdiction over public lands leading to inconsistent permitting, diffuse flight logs, and inconsistent requirements for permitted aircraft;

(ii) researchers conducting wildlife surveys or pilots flying in hazardous conditions may be exempted from altitude restrictions;

(iii) ecological studies requested by agencies and local communities require aircraft to reach remote field sites (USDOI BLM, 2017).

In addition to these management constraints, data on where all aircraft are flying over Nuiqsut's harvest use areas are absent, thwarting efforts to assess the spatial and temporal extent of conflict.

Two guiding documents for Nuiqsut, the *Nuiqsut Paisangich Heritage Cultural Plan* (Brown, 1979) and the *Draft Nuiqsut Comprehensive Development Plan* (NSB, 2015), identify engagement in resource management decision-making and continued access to their traditional harvest areas as standards for preserving quality of life and cultural identity of the community. Attainment of these goals will require better cooperation between rural Arctic communities, researchers, land users, and decision-makers. Future research efforts need to involve local people directly in the research process and produce informative tools that empower community leaders to engage in the management of their traditional lands and resources. Aircraft-harvester conflict across Arctic Alaska is unlikely to subside without community-driven research that seeks to quantify harvester responses to aircraft and how aircraft affects harvest success. Improving communication among aircraft users and local communities may be the first and most immediate step toward balancing the priorities of diverse stakeholders and mitigating conflict over the short term.

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Appendix 1A:

Literature on aircraft disturbance to humans and wildlife: results from a systematic search of Google Scholar

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Figure 1-1: Map of Alaska's North Slope and the eight Alaska Native communities that reside there. The ninth settlement of Prudhoe Bay/Deadhorse is non-Native township that was built to support oil and gas development in the Prudhoe Bay oilfield. Also depicted are airstrips, state oil and gas units (red outlines) and the National Petroleum Reserve-Alaska (green outline). The Brooks Range delineates the southern border of the North Slope. Source layers are available at the Alaska State Geospatial Clearinghouse managed by Alaska Department of Natural Resources (http://www.asgdc.state.ak.us/) and the Bureau of Land Management Alaska Spatial Data Management System (https://sdms.ak.blm.gov/sdms/download.html).

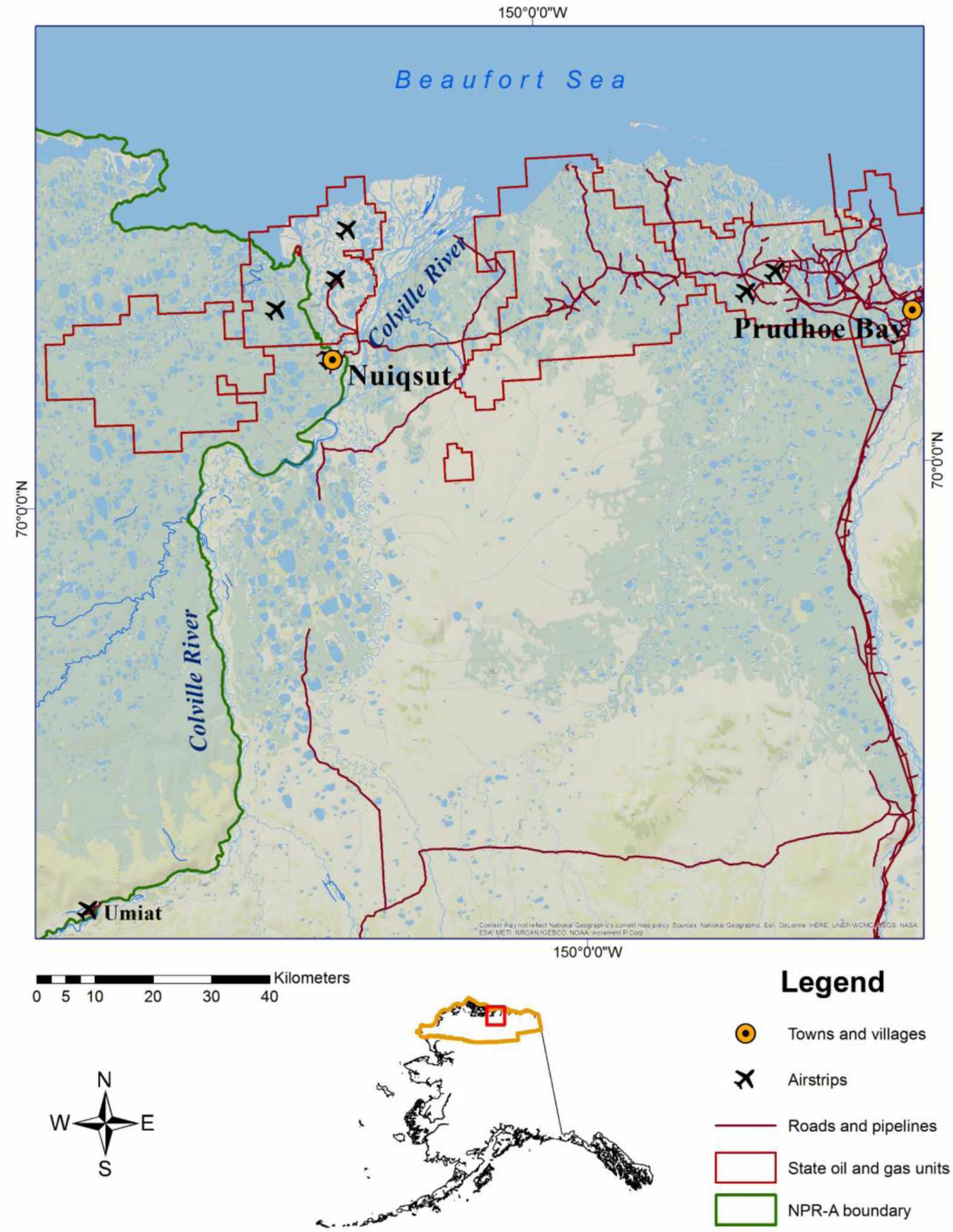

Figure 1-2: Map of the Colville River region of northern Alaska including the Alaska Native community of Nuiqsut and surrounding oil and gas infrastructure. Source layers are available at the Alaska State Geospatial Clearinghouse managed by Alaska Department of Natural Resources (http://www.asgdc.state.ak.us/) and the Bureau of Land Management Alaska Spatial Data Management System (https://sdms.ak.blm.gov/sdms/download.html).

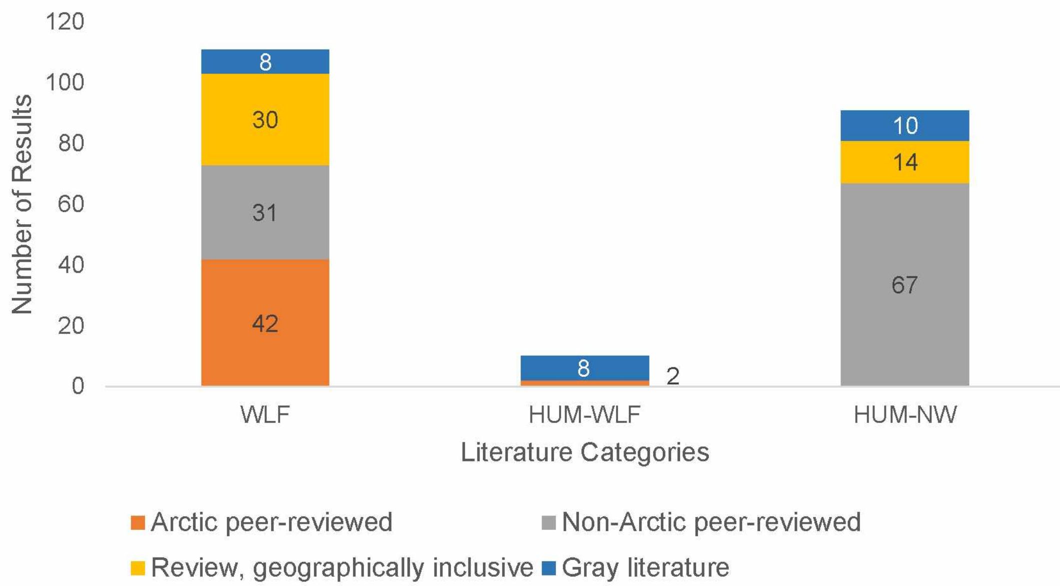

Figure 1-3: Results from a systematic search of literature available on Google Scholar for the effects of aircraft noise on human communities and wildlife. Relevant articles were categorized into three main subject areas: Wildlife (WLF), Human-Wildlife interactions (HUM-WLF), and Human-Non-Wildlife (HUM-NW). Articles within each category were examined for relevance to Arctic or Alaska ("Arctic"). Articles in the "Review" sub-category may mention Arctic regions or Arctic wildlife species. The sub-category "Gray literature" encompasses articles not published in a peer-reviewed outlet including, but not limited to, government reports, theses and dissertations, and news or popular magazine articles. The eight gray literature results in the HUM-WLF category all concerned Arctic regions.

Chapter 2: Applying soundscape ecology to quantify aircraft disturbance over traditional harvest areas in Alaska[2]

2.1 Abstract

Aircraft activity due to resource development, scientific research, and tourism is expanding across Arctic Alaska and changing social-ecological systems. Alaska Native communities report that aircraft impact their traditional harvest practices by disturbing wildlife and negatively influencing the harvest experience. Limited data restrict our knowledge about the number of aircraft flying over traditional lands. Our objective was to use soundscape-ecology methods to quantify aircraft activity around the remote Arctic community of Nuiqsut and inform disturbance mitigation processes. We provided baseline data on aircraft activity and noise levels over traditional harvest areas and postulated where aircraft could pose the greatest threat to traditional harvest practices. We deployed 20 acoustic monitoring systems in Summer 2016 along traditional harvest corridors for caribou (*Rangifer tarandus*). We conducted audiovisual analysis of sound recordings to identify aircraft signatures. A total of 7,465 aircraft noise events were captured over 21-84 days of recording during peak caribou harvest season. Aircraft activity reached 11-15 overflights per day near Nuiqsut and the surrounding industrial complex, approximately six times greater than activity levels in undeveloped areas. Aircraft sound disturbance decreased incrementally with distance from human development. Aircraft traffic around developed environments compared to local operations at U.S. airports where the average population is 908 times larger than that of Nuiqsut. Our approach demonstrated an innovative application of soundscape ecology to address conflicts related to human-wildlife interactions within rapidly changing social-ecological systems.

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[2] Stinchcomb, T.R., Brinkman, T.J., and Betchkal, D. Applying soundscape ecology to quantify aircraft disturbance over traditional harvest areas in Alaska. Prepared for submission to *Frontiers in Ecology and the Environment.*

2.2 Introduction

Human activity due to resource development, scientific research, and tourism is increasing across remote Arctic regions (Carr *et al.* 2013). In Arctic Alaska, aircraft provide vital transportation among industrial infrastructure, scientific field sites, and rural villages. Alaska Native communities have expressed concern that aircraft activity and noise may disrupt the traditional harvest of caribou (*Rangifer tarandus*). Caribou provide Alaska Native communities with nutritional, economic, and sociocultural value (Nuttall 2000; Burnsilver *et al.* 2016; Fall 2016). Disrupting harvest practices could undermine community wellbeing and cultural identity (Lambden *et al.* 2007; Smith *et al.* 2009; Loring and Gerlach 2015). We use methods from soundscape ecology to quantify aircraft activity in traditional harvest areas around the Alaska Native community of Nuiqsut on Alaska's North Slope. We are the first to address this concern using a scientific approach.

North Slope residents consistently report that aircraft activity impacts their traditional harvest success by startling caribou (USDOI BLM SAP 2010, 2014, 2016; SRB&A 2016, 2017; NSB 2016). Empirical research confirms that caribou flee and become restless when exposed to low-flying aircraft (McCourt *et al.* 1974; Calef *et al.* 1976) and military jets (Maier *et al.* 1998). Other motorized activity associated with industrial infrastructure may also displace caribou herds from their historical range (Smith *et al.* 2000; Carroll *et al.* 2005; ADFG 2007; Braem *et al.* 2011), and could change the seasonal timing of migration (Mahoney and Schaefer 2002). Some evidence suggests that caribou habituate to aircraft (Bowles 1995; Maier *et al.* 1998) or tolerate them during high-stress seasons (Murphy and Curatolo 1987), but displaced caribou seldom return to abandoned areas (Cameron *et al.* 2005; Joly *et al.* 2006).

Low-flying aircraft may also shift caribou migration routes (US Army Corps of Engineers 2016), but the spatial and temporal scales in published research are too narrow to conclude long-term distributional impacts (Vistnes and Nellemann 2008). Traditional knowledge shared by

Alaska Native harvesters and elders suggests that herds no longer pass through areas of heavy industrial activity or historical river crossings (SRB&A 2016). Arctic community members have testified that the changes in migration have the potential to reduce wild food availability (USDOI BLM SAP 2010, 2015; SRB&A 2016). If caribou are diverted, harvesters must travel farther for a harvest (SRB&A 2016), which increases the time and financial costs associated with harvest activities (Nuttall *et al.* 2004; Huntington *et al.* 2005; Sage 2012). Harvesters themselves generally avoid areas of frequent aircraft traffic, effectively removing these hotspots from the harvest landscape (Galginaitis and Petterson 1990; SRB&A 2016).

Despite the widespread and long-standing concerns of Alaska Native communities, peer-reviewed research has yet to investigate aircraft-harvester interactions and harvester response to aircraft activity (Chapter 1). The scale of this issue complicates efforts to research causal relationships and regulate aircraft operations. Certain agencies on the North Slope document takeoffs and landings within their jurisdiction (USDOI BLM 2017), but data on flight paths or private operations are not accessible. This data scarcity restricts our knowledge about the volume of traffic that occurs over traditional harvest lands during peak harvest seasons and how it might impact harvest opportunities.

Soundscape ecology offers an approach to both fill this knowledge gap and address this pressing local concern. Soundscape ecologists study the compilation of sounds in a landscape and how sound patterns inform social-ecological interactions (Pijanowski *et al.* 2011; Fristrup and Mennitt 2012; Merchant *et al.* 2015). Since 2000, the Natural Sounds and Night Skies Division (NSNSD) of the National Park Service (NPS) has implemented an acoustic inventory and monitoring program across the United States to improve visitor experience (Lynch *et al.* 2011). Since park visitors report strong negative attitudes toward aircraft overflights (Mace *et al.* 1999; Anderson *et al.* 2011), many NPS efforts focus on quantifying aircraft disturbance. The expectation for a serene experience in nature is shared by harvesters across Alaska (Cuomo *et* *al.* 2008; ADFG 2016). Soundscapes of Interior Alaska have been inventoried in Denali National Park and Noatak National Park and Preserve with a focus on aircraft activity and noise levels (Betchkal 2013, 2015).

Although the North Slope of Alaska does not contain national parks, NPS research efforts are applicable across land jurisdictions. Through a soundscape-ecology approach, acoustic monitoring systems record sounds arising from the background (or “ambient”) environment (e.g., wind, water, thunder), biological sounds (e.g., wildlife calls), and noise (e.g., motorized vehicles, industrial noise, gunshots, human voices). Noise impacts to humans and wildlife depend dually on the number of aircraft that fly over and the intensity of the noise they produce (Bleich *et al.* 1994; Swanson 2002; Barber *et al.* 2010). Acoustic monitoring systems can capture both metrics in the field. Subsequent audiovisual analysis of acoustic signals in the lab can quantify the impacts of aircraft noise on the local soundscape.

Here, we conduct acoustic monitoring of traditional harvest areas on the North Slope of Alaska around the community of Nuiqsut. This research was implemented following a request by the Kuukpik Subsistence Oversight Panel. We apply NPS acoustic monitoring methods to quantify aircraft noise disturbance over Nuiqsut’s caribou harvest corridors. We hypothesize that aircraft activity will decline with distance from Nuiqsut and the surrounding industrial complex. We report baseline observations of aircraft impacts to Nuiqsut’s caribou harvest areas (SRB&A 2017) during Summer 2016.

2.3 Methods

2.3.1 Study Area

Nuiqsut (70.2175° N, 150.9764° W) is a rural village located on the North Slope of Alaska, approximately 29 km inland from the Arctic Ocean along the Colville River delta (Brubaker *et al.* 2014). The surrounding landscape is flat, low-lying tundra broken by a patchwork of lakes and waterways. Although annual precipitation is light, averaging 13-15 cm rainfall and 51 cm snowfall (NSB 2015), the tundra remains covered by snow and ice in the winter due to a thick layer of permafrost (Brubaker *et al.* 2014). Industrial oil and gas infrastructure partially envelops Nuiqsut to the northeast around the Colville delta, to the northwest, and to the east (Figure 2-1). New developments are underway to the west of the village.

Local temperatures range from -49 to 26 °C with 297 days below freezing (Brubaker *et al.* 2014; NSB 2015). From 1949-2016, mean annual temperatures have risen by 4 °C in the winter and 2 °C in the summer (Alaska Climate Research Center 2016). Winds carry over the flat tundra at speeds between 5 and 16 m/s (NSB 2015), and winter winds can drop temperatures below -59 °C (Brubaker *et al.* 2014). At 70.2172 N, Nuiqsut receives 24 hours of daylight in the summer and under 3 hours of “civil twilight” in the winter, when the sun remains just below the horizon.

The population of Nuiqsut (N = 411, US Census Bureau 2016) is 89% Alaska Native Inupiat (NSB 2015). Nuiqsut residents use the Colville River (Figure 2-1) to access fish and wildlife resources (Braem *et al.* 2011; SRB&A 2016). Terrestrial mammals make up just under 30% of Nuiqsut’s annual traditional harvest, and caribou make up 22-28% of total usable harvest weight per capita (George and Fuller 1997; Brown *et al.* 2016), representing the most important terrestrial species for Nuiqsut (Brower and Hepa 1998). Traditional harvest areas extend approximately 90 km south of the community along the Colville River, west of the community approximately 20 km into the National Petroleum Reserve-Alaska (NPR-A, Figure 2-1) and northeast of the community around the Colville River delta. Peak harvest season for caribou occurs from June through September, aligning with the peak season for industrial, commercial, and research activities involving aircraft.

2.3.2 Acoustic Monitoring Methods

To quantify aircraft activity and noise levels over Nuiqsut's traditional harvest areas during peak caribou harvest season, we deployed 20 acoustic monitoring systems from June 03 to August 28, 2016. We collaborated with Nuiqsut community organizations and tribal entities (e.g., Kuukpik Subsistence Oversight Panel, Caribou Subsistence Monitoring Panel) to establish our monitoring sites every 10 km along traditional harvest corridors (WebTable 2-1). We utilized an inexpensive consumer-grade digital audio recorder (Roland R-05, Roland Corporation 2010, Los Angeles, CA) calibrated to provide absolute sound pressure level (SPL) measurements (Mennitt and Fristrup 2012).

Our systems recorded sound continuously for 30-day intervals. We avoided the use of aircraft for transport to our field sites and opted instead to travel by boat with a local driver. We collected all soundscape systems in early September before river freeze-up. Environmental conditions prevented data retrieval from two devices. After downloading the sound data, we used the AUDIO2NVSPL software (NPS 2008, Fort Collins, CO) to convert mp3 audio files into one-second spectral SPLs, a format appropriate for generating sound spectrograms.

To identify aircraft sound events, we conducted audiovisual analysis of spectrograms using the Sound Pressure Level Annotation Tool (SPLAT) from the Acoustic Monitoring Toolbox version 1.0.5591 (NPS 2008, Fort Collins, CO) following protocols outlined by the NSNSD (Lynch *et al.* 2011). We define one aircraft event as an unbroken period over which aircraft signals are audible, from the time one signal enters audibility in the audio recording to the time the last fades out of audible range. We consider each event as one instance of aircraft disturbance. We annotated each event at a monitoring site with a source code according to aircraft type: high-altitude jet, propeller plane, or helicopter (Appendix 2A).

Comparing levels of aircraft and watercraft disturbance may be of interest to residents, managers, soundscape ecologists, and wildlife biologists. During the summer, most harvesters in Nuiqsut use watercraft to access caribou harvest areas. We therefore tagged watercraft signatures during audiovisual analysis and extracted the same metrics as those for aircraft, described below.

2.3.3 Quantifying Aircraft Disturbance

To examine our hypothesis that aircraft activity declines with distance from industrial and civil development, we calculated the average distance of each site from the Nuiqsut airport and the adjacent oil and gas complex. We compared sound metrics in three regions: developed areas (<15 km from development); intermediate areas (between 15-30 km from development); and undeveloped areas (>30 km from development). We also examined temporal trends in aircraft events using the Data Clock tool in ArcMap 10.4.1 (ESRI 2016).

We chose Sound Exposure Levels (SEL) and daily Noise Free Intervals (NFI) to characterize aircraft noise (Appendix 2B). To describe the natural component of the soundscape, we chose Natural Ambient Sound Level (L_{nat}). For each development region, we report the range of observed L_{nat} values, median SEL, and median NFI. We used a combination of Python v 3.5.1 and R v 3.2.4 (R Development Core Team 2016) to extract activity and noise metrics.

To visualize median NFIs across the study area, we used the Kernel Interpolation with Barriers tool in the Spatial Analyst toolbox in ArcMap 10.4.1 (ESRI 2016). We clipped this heat map to a 10-km buffer around each monitoring site and overlayed an additional 5-km radius to correct for the estimated range of our monitoring systems. Our heat map provides a preliminary estimation of aircraft disturbance over space. However, we recommend interpretive caution due to the following caveats:

(i) the Kernel Interpolation with Barriers method does not account for sound attenuation;

(ii) considerable data gaps exist west of Nuiqsut and over 50 km upriver. Inference in these areas is limited and prediction error increases accordingly;

(iii) the standard error map should always be referenced when interpreting disturbance levels.

2.4 Results

Acoustic monitoring systems recorded 21-84 days of sound from 03 June to 28 August 2016 (WebTable 2-1), capturing a total of 7,465 aircraft events (Table 2-1). Aircraft activity was concentrated around human developments, where event rates exceeded 11 aircraft per day (Table 2-1). Most aircraft occurred between the hours of 0700 and 2000, with peak daytime activity falling on Wednesdays and Fridays (WebFigure 2-1). In undeveloped areas, event rates dropped to one aircraft per day (Table 2-1) and showed little evidence of a temporal pattern (WebFigure 2-1). Activity at intermediate sites fell in between developed and undeveloped levels, with median of 7 events per day (Table 2-1).

Median L_{nat} ranged from 25.3 to 47.4 dBA over the study area, with the highest and lowest L_{nat} values occurring in intermediate regions. Aircraft median SEL ranged from 55 to 69 dBA (WebTable 2-2), and was 5 dBA greater in developed environments compared to undeveloped environments (Table 2-1). Maximum SELs reached 103 dBA in undeveloped environments, but SELs of individual aircraft events showed wide variation over the study area (WebTable 2-2).

The median NFI in developed environments fell below one hour. The shortest median NFIs (0.5 hrs, or two aircraft every hour) occurred near the village center and at sites located between industry airstrips. Our heat map shows that NFI durations increased incrementally with distance from the developed Colville Delta (Figure 2-2). A region 50-80 km upriver from Nuiqsut experienced the lowest disturbance levels, with estimated NFIs between 13 and 22 hrs (Figure 2-2).

Watercraft disturbance levels (range median 61-65 SEL dBA) compared to aircraft sound levels (range median SEL 58-64 dBA) across the study area (Table 2-1). However, maximum watercraft SELs only exceeded 90 dBA in one case, whereas maximum aircraft SELs exceeded 90 dBA at 40% of our sites (WebTable 2-2). Watercraft were most frequently detected around the developed Colville delta at a rate of 5 events per day (Table 2-1).

2.5 Discussion

We found a close association between aircraft activity and developed environments on the North Slope. Supporting our hypothesis, the greatest disturbance from aircraft occurred within 15 km of Nuiqsut and nearby industrial infrastructure, and disturbance levels decreased incrementally with distance from this development complex. Activity levels within 30 km of Nuiqsut (combined median of nine aircraft per day) compared to local (non-itinerant) operations at 10 airports in the continental U.S. over the same period (June-Aug 2016, FAA 2017). These airports support an average population of 373,284 people, over 900 times the size of Nuiqsut.

Watercraft disturbance paralleled the pattern of aircraft disturbance, declining over 30 km away from development. However, watercraft occurred at 30% the rate of aircraft in developed and intermediate regions. Low watercraft activity in undeveloped regions remains consistent with lower caribou harvest activity on the upper Colville River (SRB&A 2016). These data suggest that Nuiqsut harvesters typically travel less than 30 km from the village. Traveling farther upriver generates additional costs for the harvest including time and watercraft fuel (Nuttall *et al.* 2004; Huntington *et al.* 2005; Brinkman *et al.* 2014). It also introduces logistical challenges such as reduced navigability in shallower waters. Thus, most harvest may be occurring where aircraft disturbance is concentrated.

L_{nat} measurements at 70% of our sites compared to existing ambient conditions of rural areas in the western and midwestern U.S., between 30 and 38 dBA (Mennitt *et al.* 2013). Estimates of ambient sound above 40 dBA in developed areas may be influenced by noise from oil and gas operations (Foch and Burke 1985; Radtke *et al.* 2016). In intermediate or undeveloped areas, high L_{nat} levels can be influenced by swift-moving water (Betchkal 2013) or windy coastal conditions (Lee and MacDonald 2012a, 2012b; NPS 2017). Our L_{nat} levels away from development were consistent with levels modeled across northern interior Alaska (derived using methods from Mennitt *et al.* 2013), especially in other riparian areas (Betchkal 2015). Since we were among the first to record environmental sound on the North Slope, our L_{nat} measurements could refine the ambient sound model for northern Alaska.

Our aircraft disturbance data will facilitate future examination of the North Slope soundscape and enhance assessments of aircraft impacts to harvest practices. A Nuiqsut harvester may experience an SEL of 60 dBA from a typical aircraft encounter. Under a direct overflight, SELs could exceed 90-100 dBA. Loud noise can interfere with human conversation (USDOI Bureau of Reclamation 2008), induce annoyance (Mace *et al.* 1999), and, at intense levels, may cause physical and psychological stress (Meister and Donatelle 2000; USDOI Bureau of Reclamation 2008). Low-altitude overflights are likely to startle caribou (Calef *et al.* 1976; Webster 1997; Anderson 2007), which may compromise harvest opportunities. SEL depends on the distance, altitude, and direction of the aircraft from the harvester, so disturbance levels are unpredictable unless harvesters know when and where aircraft will fly. This unpredictability could amplify harvester frustration (Hatfield *et al.* 2002).

Whereas individual aircraft SELs were highly variable across the study area (WebTable 2-2), our NFI measurements showed a clear association between sound disturbance level and proximity to human development. NFIs at our most-disturbed sites compared to NFIs at monitoring sites under known FAA flight routes in Interior Alaska (Betchkal 2013). Because the rate of change for NFI length decreases as event rates increase, restricting the number of aircraft that fly over environments where NFIs drop below one hour may do little to reduce disturbance levels.

Our spatially explicit data for aircraft disturbance could be overlayed with a map of caribou harvest use by Nuiqsut residents (see SRB&A 2016, 2017). This would allow researchers to examine where aircraft might have the greatest impact on harvest opportunities. Based on our findings that illustrate high watercraft (i.e., local harvesters) and aircraft activity in the same general area, we speculate regular circumstances where direct conflict is likely. Few studies have documented harvester behavior in relation to aircraft or other human activity. Future research should integrate real-time tracking of harvester, caribou, and aircraft movements to more closely examine the interactions within this social-ecological system.

2.5.1 Future Recommendations

Our data indicated that Nuiqsut harvesters who travel farther from development are less likely to encounter an aircraft. Yet undeveloped regions showed the greatest difference between median and maximum aircraft disturbance levels. Remote environments in the southwestern and western U.S. experience some of the longest periods of audible human-derived noise, suggesting that the quietest soundscapes may be the most vulnerable to disturbance from distant aircraft (Lynch *et al.* 2011). Increasing aircraft traffic over undeveloped areas may thus cause a sharp rise in disturbance initially, but traffic could eventually reach the level of developed environments, at which the effect of additional aircraft becomes negligible. By this reasoning, low-disturbance areas could be at greater risk for future aircraft disturbance than regions already subject to high aircraft activity. Future monitoring and mitigation efforts could focus on areas of low-to-intermediate disturbance and high annual harvest use to minimize further impacts to Nuiqsut’s traditional harvest practices.

We speculate that true aircraft disturbance levels were higher than we estimated in 2016. Our reliance on local boat guides, rather than aircraft, to access our monitoring sites caused logistical difficulties that resulted in considerable data loss at sites in undeveloped regions and in vital harvest areas to the west of Nuiqsut. Additionally, oil prices dropped prior to implementation of our study, which likely decreased oil industry activity and the efforts of agencies and private researchers that are indirectly supported by oil revenues. As new oil developments proceed, and oil prices rebound, we expect aircraft use to intensify over traditional lands to the west of Nuiqsut along Fish Creek (Figure 2-2). Fish Creek carries economic and sociocultural significance for many Nuiqsut residents who visit familial camps every summer (USDOI BLM SAP 2015), but it could experience substantial aircraft traffic from ongoing development. Continued monitoring efforts could improve our understanding of the social impacts of aircraft disturbance in this important harvest area for the Nuiqsut community.

2.6 Conclusion

Despite the gaps in our dataset, acoustic monitoring was an effective method to document aircraft disturbance around a remote Arctic environment that is relevant to indigenous harvesters. We successfully quantified aircraft activity over traditional harvest areas for the Alaska Native community of Nuiqsut using calibrated consumer-grade digital audio recorders. Since our systems are low-cost and user-friendly, they could be implemented in communities across Alaska that share the concerns of Nuiqsut residents for traditional harvest practices. Our success has already prompted requests to conduct this research around other North Slope villages.

Acoustic data are becoming important and widely applicable tools for studying social-ecological systems. Multi-year studies could deconstruct interactions within social-ecological systems and system responses to environmental change. Stakeholder engagement in soundscape research could facilitate the decision-making process by enhancing the relevance of scientific efforts to local communities. Soundscape ecology offers emerging methods for conducting community-driven research and understanding how social-ecological systems change over space and time.

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Table 2-1: Metrics of aircraft and watercraft disturbance from 2016 acoustic monitoring sites around the Colville River region in northern Alaska. Site-based data were summarized across three regions: developed (<15 km from infrastructure), intermediate (15-30 km from infrastructure), and undeveloped (>30 km from infrastructure). We report the sum of aircraft events and the median value for daily event rates, Sound Exposure Levels (SEL), Noise-Free Intervals (NFI) in each region. We provide Median Absolute Deviation (MAD) as an index for variability of each disturbance metric. L_{nat} is the existing ambient sound level in the absence of aircraft activity and serves as a baseline environmental condition. Because L_{nat} is spatially explicit, we provide the range of median L_{nat} values that occurred in each region.

	Range Median L_{nat} (dBA)[a]	**Total Events**	**Median Daily Events**	**MAD Daily Events**	**Median SEL (dBA)**	**MAD SEL (dBA)**	**Max SEL (dBA)**	**Median NFI (hrs)**	**MAD NFI (hrs)**
Aircraft									
Developed (n=5)	33.8-40.2	4046	12	6.4	64	8	94	0.5	4
Intermediate (n=7)	25.3-47.4	2839	7	4.7	60	8	101	1	4
Undeveloped (n=7)	28.9-37.8	565	2	1.8	58	7	103	13	15
Average, all sites [b]	n/a	7465	6	n/a	61	n/a	89	5	n/a
Watercraft									
Developed (n=5)	33.8-40.2	1397	5	4	65	6	89	1	9
Intermediate (n=7)	25.3-47.4	865	3	3.2	63	8	96	1	16
Undeveloped (n=7)	28.9-37.8	668	2	1.4	61	7	84	2	40
Average, all sites [b]	n/a	2930	2	n/a	62	n/a	79	4	n/a

[a]dBA = A-weighted decibels, a standard unit of sound pressure normalized to human hearing.

[b]Average median value, except for Total Events which is summed across sites.

WebTable 2-1: Acoustic monitoring sites deployed during the summer of 2016 along the Colville River system in northern Alaska.

Site Name	Latitude	Longitude	Date Deployed	Recording End Date	Days Recorded	Mean Distance (km) from Infrastructure[a]
NIGLIQ2	70.3312	-151.0809	3-Jun	26-Aug	84	11.1
NIGLIQ1[d]	70.2422	-151.0004	3-Jun	10-Jul	38	11.1
ICERD	70.2365	-150.8255	3-Jun	28-Aug	84	12.5
CD3	70.3324	-150.7147	3-Jun	28-Aug	83	15.3
FSHCK2[b]	70.2967	-151.2875	25-Jun	9-Jul*	5	15.8
FSHCK1	70.3599	-151.2919	25-Jun	23-Jul*	23	17.2
ITKILLIK1	70.1517	-150.9547	2-Jun	27-Aug	84	19.3
FSHCK3[b]	70.3161	-151.4860	4-Jun	10-Jul*	29	22.6
USGS	70.4636	-150.7561	3-Jun	21-Aug	80	24.1
ITKILLIK2	70.1055	-150.8368	26-Jun	19-Aug	54	25.2
CLVL2	70.0741	-151.0655	2-Jun	27-Aug	76	27.5
FSHCK4[b]	70.2727	-151.6857	4-Jun	24-Jun	15	29.7
OCNPT	70.0719	-151.3822	2-Jun	27-Aug	66	30.3
CLVL4	70.0002	-151.5933	2-Jun	28-Jul	51	41.4
CLVL5	69.8941	-151.5659	2-Jun	27-Aug	84	50.6
UMIRUK[b,c]	69.7955	-151.5646	2-Jun	5-Jul	32	60.3
ROCKY[b]	69.7137	-151.5077	13-Jul	13-Sep	33	67.9
SHORTY[b,c]	69.6370	-151.4347	4-Jun	24-Jun	21	75.2
ANKTVK[b,c]	69.5459	-151.4539	25-Jun	18-Aug	21	85.1
UMIAT	69.3605	-152.1234	25-Jun	28-Jun	41	113.2

[a]Average distance from airstrips on the Colville River delta including Nuiqsut airport and landing strips on oil developments (see Figure 2-1).

[b]Site could not be reached due to river conditions and was abandoned 26-27 July 2016.

[c]Site was lost to the river.

[d]Site could not be successfully re-wired and was taken down 28 July 2016.

WebTable 2-2: Site-based metrics of aircraft activity and sound disturbance from 2016 acoustic monitoring in the Colville River region of northern Alaska. We report overall event counts, median daily event rates, Sound Exposure Levels (SEL), and Noise-Free Intervals (NFI) as measures of aircraft disturbance. Median L_{nat} is the level existing ambient sound in the absence of aircraft activity and serves as a baseline environmental condition at each site. Metrics were extracted from annotated sound data using Python v 3.5.1 and R v 3.2.4 software.

Site	Days Recorded	Mean distance (km) to Infrastructure*	Median L_{nat} (dBA)‡	Total events	Median Daily Events	Max Daily Events	Median SEL (dBA)	Max SEL (dBA)	Median NFI (hrs)	Max NFI (hrs)
NIGLIQ1	38	11.1	35.5	565	14	35	65.2	89.3	0.5	8.2
NIGLIQ2	84	11.1	33.8	940	11	40	61.0	91.6	0.6	12.9
ICERD	84	12.5	36.2	1090	12	40	62.0	94.4	0.5	10.7
CD3	83	15.3	40.2	985	12	37	69.0	94.1	0.5	12.4
FSHCK2	5	15.8	40.2	15	4	6	60.6	86.8	3.1	15.8
FSHCK1	23	17.2	35	145	7	36	57.9	83.8	1.6	16.8
ITKILLIK1	84	19.3	40.3	818	8	42	64.2	101.2	0.8	11.5
FSHCK3	29	22.6	32.9	217	8	18	61.8	82.1	1.6	12.2
USGS	80	24.1	47.4	574	7	22	60.2	92.2	0.7	18.5
ITKILLIK2	54	25.2	25.3	408	6	37	54.9	78.8	1.3	12.4
CLVL2	76	27.5	36.3	553	6	23	59.9	95.0	1.5	15.5
FSHCK4	15	29.7	33.1	124	7	15	60.9	80.4	1.3	10.1
OCNPT	66	30.3	37.8	288	4	13	57.7	89.2	2.4	26.4
CLVL4	51	41.4	31.4	114	3	8	56.4	100.5	4.4	39.9
CLVL5	84	50.6	33.9	77	1	13	56.1	102.5	10.2	113.3
UMIRUK	32	60.3	28.9	16	1	2	60.3	82.4	30.8	134.4
ROCKY	33	67.9	30.8	31	1	3	60.2	78.1	20.5	62.1
SHORTY	21	75.2	35.3	18	1	3	64.4	88.6	20.8	75.6
ANKTVK	21	85.1	37.7	21	2	6	63.9	87.3	3.9	97.2
UMIAT	41	113.2	35.6	466	10	62	67.8	89.1	0.5	11.4

* Average distance from airstrips on the Colville River delta including Nuiqsut airport and landing strips on oil developments

‡dBA = A-weighted decibels, a standard unit of sound pressure normalized to human hearing.

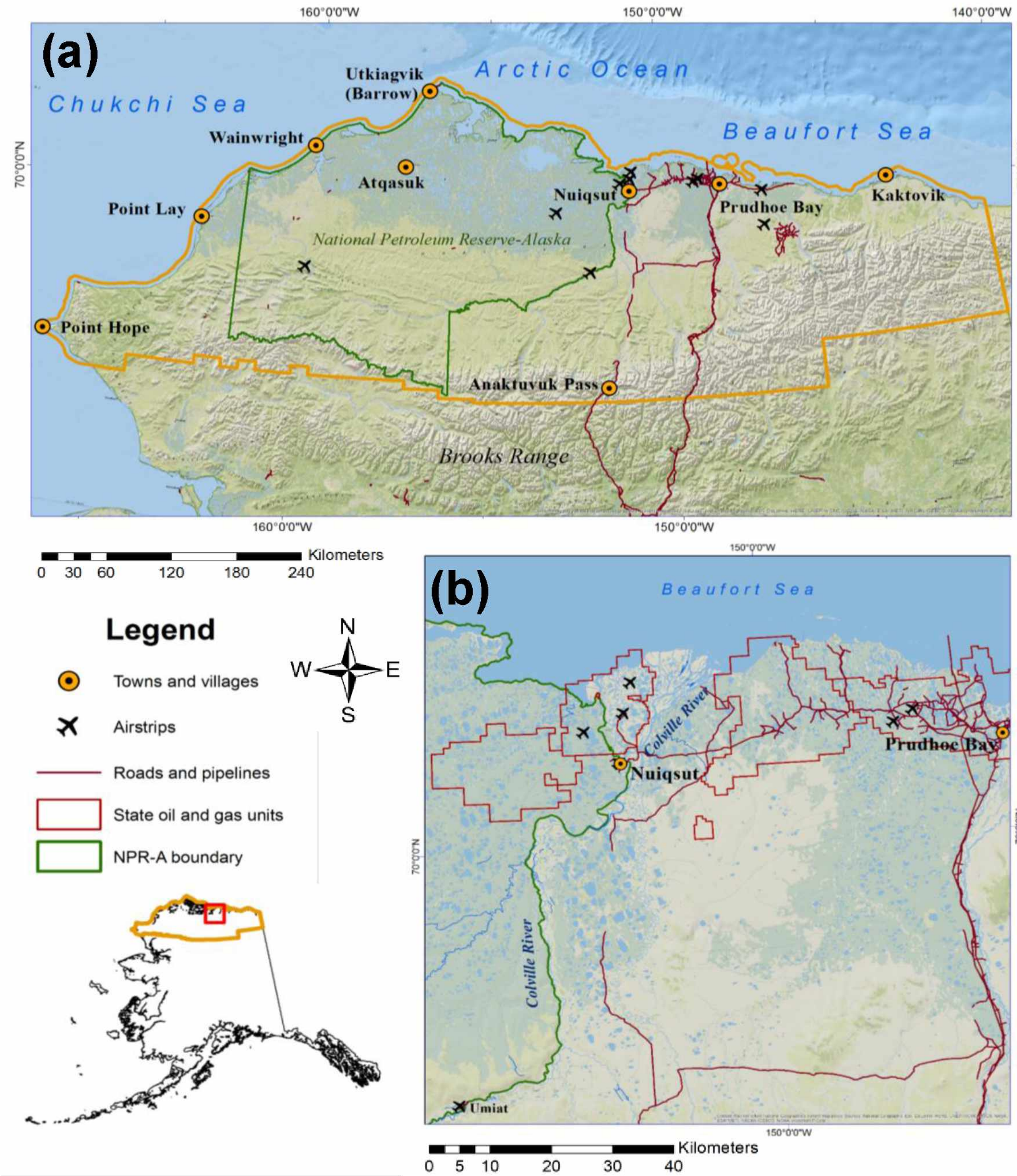


Figure 2-1: Study area map of (a) the North Slope of Alaska, including the Alaska Native community of Nuiqsut and surrounding oil and gas developments; and (b) the Colville River region where 20 acoustic monitors were deployed in the summer 2016 to capture aircraft disturbance over Nuiqsut's traditional caribou harvest lands. Source layers are available at the Alaska State Geospatial Clearinghouse managed by Alaska Department of Natural Resources (http://www.asgdc.state.ak.us/) and the Bureau of Land Management Alaska Spatial Data Management System (https://sdms.ak.blm.gov/sdms/download.html).

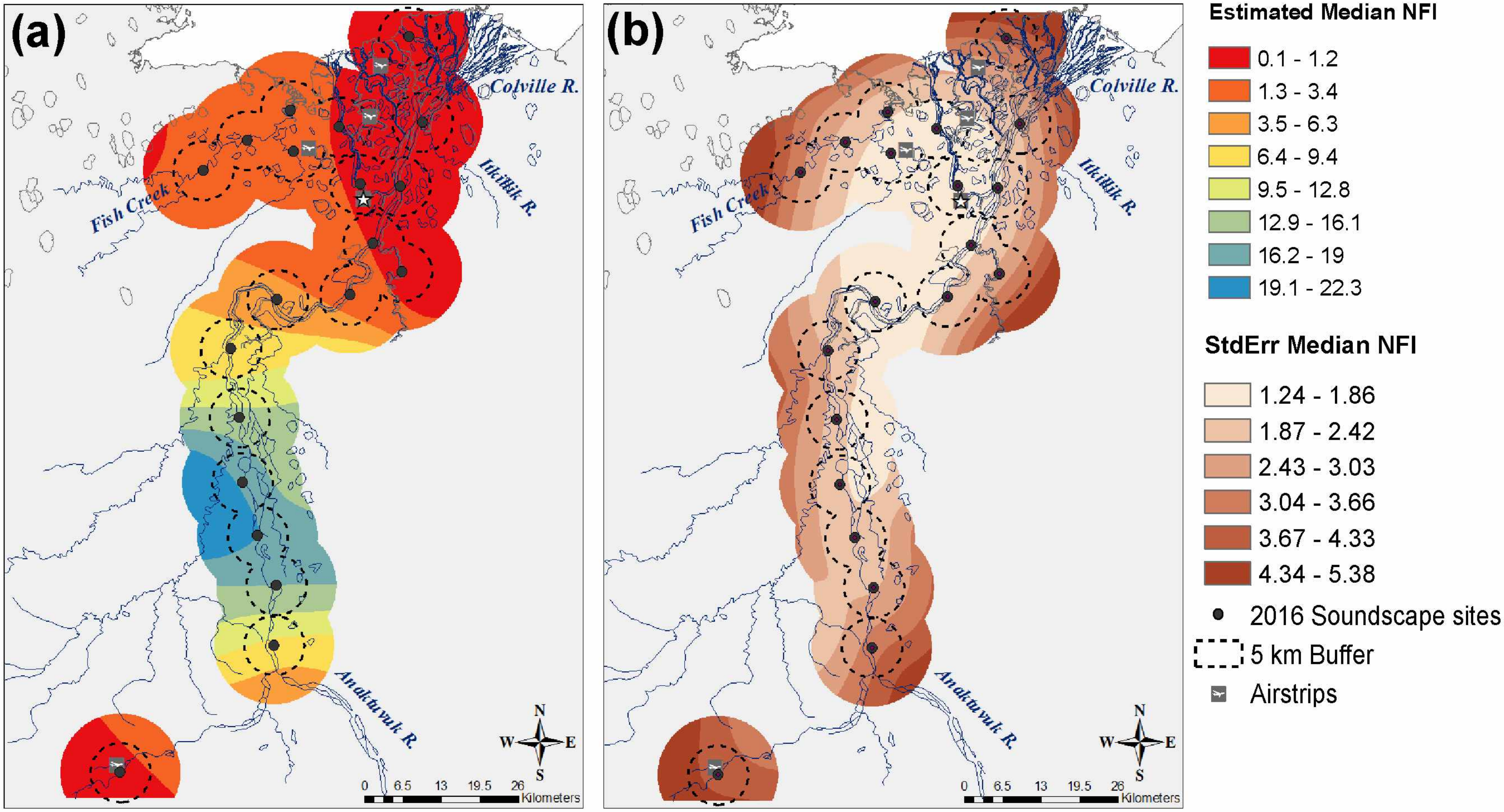
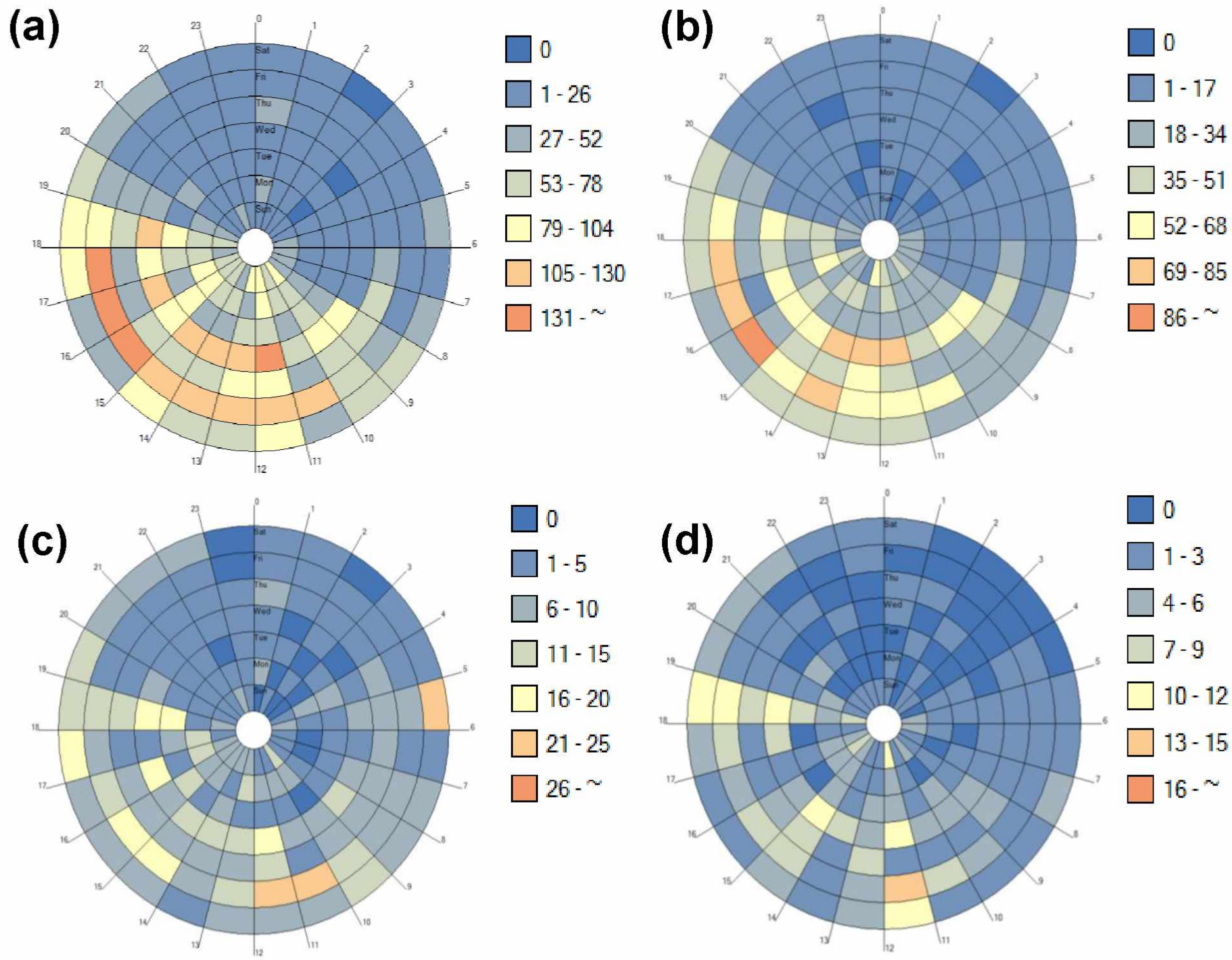


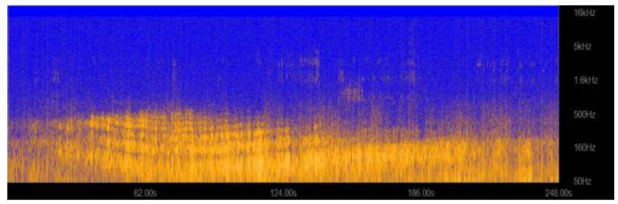
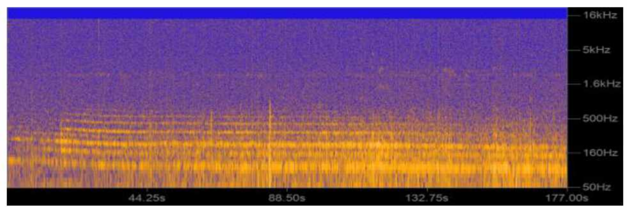
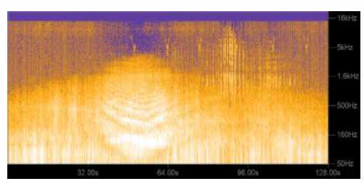
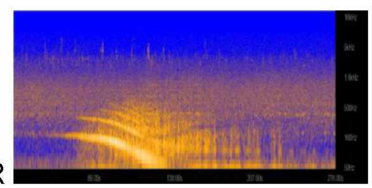
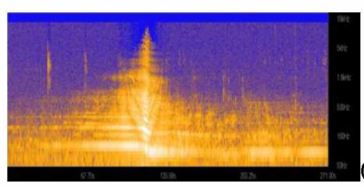
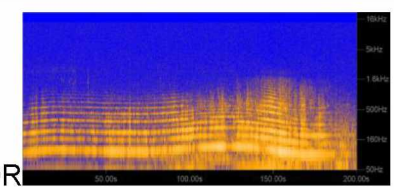
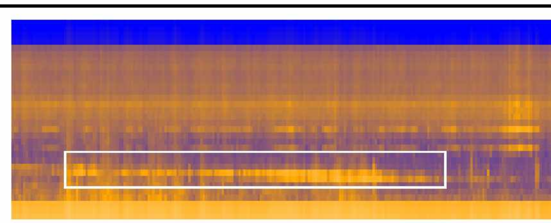
Figure 2-2: Estimated distribution of median Noise Free Intervals (NFI) over the study area (a) generated by Kernel Interpolation with Barriers in ArcMap 10.3. Disturbance level is presented on a scale from cool color (blue, long NFI and low disturbance) to warm and hot color (red, high disturbance). Red areas experience the shortest intervals between aircraft events, and thus the greatest potential disturbance. The corresponding standard error (b) must be considered when interpreting these heat maps. Data are limited for the four southernmost sites (excluding the Umiat airstrip) and the four sites along Fish Creek.

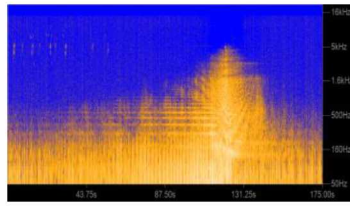
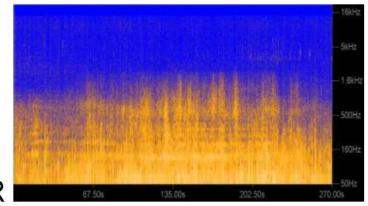
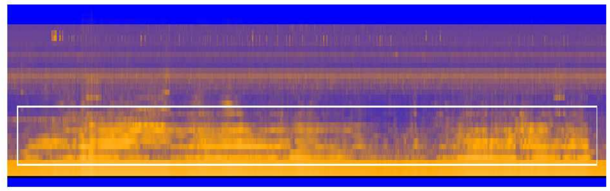
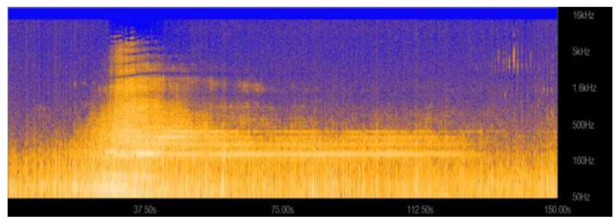
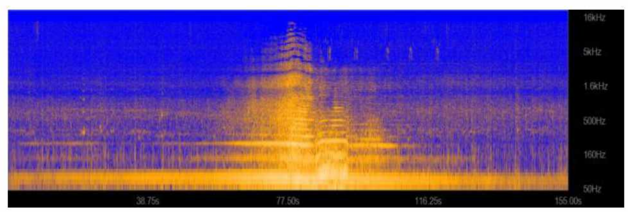


WebFigure 2-1: “Data Clocks” displaying the temporal distribution of aircraft noise events by day of the week (rungs, Sun-Sat from center) and hour of the day (slices, 0-23 from top). Events are totaled over June 03 to August 28, 2016, across the study area (a) and by region: Colville River delta (b), upper Colville River (c) and Fish Creek (d). Aircraft activity appears to occur between the hours of 0700 (7 am) and 2000 (8 pm), with few events in the nighttime hours. Wednesday and Friday experience the highest concentration of events. This temporal trend is evident at sites around the Colville delta, but not in the other two regions.

Appendix 2A:

Sound source ID codes and sound signatures for aircraft and watercraft sounds identified using the Sound Pressure Level Annotation Tool

1	Aircraft, unspecified or unknown	Used when aircraft type could not be determined
1.1	High-altitude jet	
1.2	Propeller noise, distant or indistinguishable	
1.21	Propeller jet	 OR 
1.22	Lightweight propeller plane, e.g., Cessna	 OR 
1.24	Low-frequency bands	

1.3	Helicopter	 OR 
3	Watercraft, unspecified	
3.1	Outboard boat	
3.4	Jet boat	

Appendix 2B:

Definitions of Sound Disturbance Metrics

Natural Ambient Sound Level (L_{nat}): an estimate of what the acoustical environment might sound like in the absence of human-derived noise. For each hour of data, the loudest percent of sound is removed to calculate the level of sound L_x that would exist in the absence of anthropogenic noise:

$$x = \frac{100 - p}{2} + p$$

where *p* is the percent time audible for anthropogenic sound sources; *x* represents the exceedance level (L_x) equivalent to L_{nat} for that hour. For example, if *p* = 35, *x* = 60 and $L_{nat} = L_{60}$ or the level of sound exceeded 60% of the time during that hour (Lynch *et al.*, 2011)[3]. We took the median L_{nat} across all hours at each site.

Sound Exposure Level (SEL): the total acoustic energy of a noise event, normalized to a one-second duration. It can be used to compare the acoustic energy impact of events with different durations.

Noise Free Interval (NFI): the amount of time between two aircraft sound events. It may be the closest quantification of how animals and humans on the ground experience quiet. It depends only on whether a source is detected or not, and is relatively insensitive to small changes in the ambient environment. We thus consider NFI to be a robust metric for baseline sound disturbance.

[3] Lynch E, Joyce D, and Fistrup K. 2011. An assessment of noise audibility and sound levels in U.S. national parks. *Landscape Ecology* **26:** 297-1309.

Conclusion

Indigenous communities in Arctic Alaska express almost universal concern that aircraft activity disturbs wildlife and threatens their traditional harvest practices. Their frustration has been documented for over four decades in government reports, public testimony, and privately contracted research (USDOI MMS, 1979; USAED, 1996; USDOI BLM, 1997; SRB&A, 2009; USDOI BLM SAP, 2010, 2012–2014). This issue carries importance for managers who aim to balance the needs of aircraft operators with the rights of public land users and Alaska Native communities, and for researchers who need to access remote Arctic field sites while maintaining respectful relations with local communities. It carries perhaps the greatest importance for Alaska Native communities who depend on the traditional harvest of wildlife for their wellbeing and for the perpetuation of their culture.

Despite the extent of aircraft-harvester conflict across Alaska's North Slope, the impacts of aircraft activity on traditional harvest practices remain understudied by the scientific community. My research sought to highlight the need to research aircraft-harvester interactions, to understand why aircraft disturb Alaska Native harvesters, and to use soundscape ecology to quantify aircraft disturbance around a North Slope community.

In Chapter 1, I quantified the extent of current scientific knowledge on aircraft-wildlife-human relations through a meta-analysis of literature available on Google Scholar. I found that not a single peer-reviewed article investigated the conflict between aircraft users and harvesters in the Arctic. Of the literature I examined, only 4.5% mentioned impacts to traditional harvest practices to some degree. These results revealed a severe deficiency in scientific research on the social and cultural consequences of aircraft in rural Arctic communities. The scale over which aircraft-harvester interactions occur complicates our capacity as researchers to determine causal relationships. However, several opportunities exist for researchers to begin to disentangle aircraft-harvester interactions, and for managers to mitigate local conflicts.

I highlighted the need for increased communication among aircraft users and local communities to mitigate conflict over the short term. Notifying harvesters about aircraft trajectories could reduce the unpredictability of aircraft activity that may contribute to harvester frustration (Pepper et al., 2003; Hatfield et al., 2002). Conflict Avoidance Agreements (e.g., USDOI BLM, 2017) may be the most immediate strategy to balance the priorities of diverse stakeholders and protect traditional access to wild resources (Brown, 1979).

My review of aircraft-harvester conflict showed that a lack of baseline data on aircraft activity over the North Slope constrains both research and management efforts. Soundscape ecology offers one method that could shrink this data gap. By monitoring continuous environmental sound, soundscape systems could capture aircraft activity from all aircraft users in the region and determine when and where aircraft occur over traditional harvest lands. This information could be used by local communities to develop communication plans and Conflict Avoidance Agreements with aircraft operators. This information also could be used by wildlife ecologists to explore the impacts of aircraft on wildlife physiology and behavior.

My study was the first to use a soundscape-ecology approach to address aircraft-harvester conflict in Nuiqsut, an Alaska Native community on the North Slope. I confirmed that soundscape methods are effective for capturing aircraft disturbance levels over traditional harvest lands. I achieved my goals of quantifying aircraft event rates and noise levels, and remaining relevant to local priorities throughout the research process. My community-driven methods were embraced by Nuiqsut. Other North Slope communities have requested that aircraft monitoring studies be conducted in their traditional harvest lands (USDOI BLM SAP, 2016a, 2016b)

Now that I have collected data about aircraft disturbance, future research may overlay aircraft disturbance levels with data on the behavior of Nuiqsut harvesters (SRB&A, 2016, 2017) to examine where traditional harvest practices face the greatest threat from aircraft activity. This information could enable Nuiqsut harvesters to develop Conflict Avoidance Strategies and negotiate agreements with aircraft operators.

As requested by other communities, my low-cost acoustic monitoring methods could be expanded across the North Slope and implemented over multiple years to examine how aircraft activity varies over space and time. Improvements to my methodology could allow for the identification and tracking of individual aircraft. Involving local harvesters to collect on-the-ground observations, or integrating sound monitoring systems with radar technology may refine the resolution of aircraft signals and allow for the discrimination among different aircraft models. Deploying acoustic monitoring systems in a grid formation may enable researchers to track flight paths over traditional lands. Doing so would require close collaboration with and assistance by the local community to access every monitoring site without the use of an aircraft. Cross-validating data from other agencies, researchers, or private pilots could corroborate acoustic data and provide insight into the distribution of aircraft users over the region.

One question that limits current scientific understanding of aircraft-human interactions is whether harvester frustration is driven by the presence of an aircraft, the noise of an aircraft, the sight and sound in tandem, or the perceived impacts on wildlife. Studies in urban environments suggest that noise exposure levels from loud aircraft contribute more to annoyance ratings than overflight frequencies (Rylander et al., 1980). However, non-acoustical factors (Laszlo et al., 2012) also induce annoyance at relatively low levels (40 dBA), including interference with one's experience of nature (Mace et al., 1999). Frustration with aircraft overflights during harvest activities is widespread across Alaska (ADF&G, 2016), but the degree to which sound levels influence this frustration remains unknown. Understanding why harvesters avoid aircraft will be crucial to managing user conflicts over the long-term.

Scientific knowledge of caribou responses to aircraft noise also remains incomplete. Studies are observational and conducted on a small sample of individual animals over the short term (e.g., McCourt et al., 1974; Calef et al., 1976; Maier et al., 1998). Chronic stress could carry fitness consequences (Geist, 1971; Murphy and Curatolo, 1987; Harrington and Veitch, 1992; Luick et al., 1996), but stress responses have not been examined in barren-ground caribou. Noise exposure monitors can be affixed to caribou GPS collars (Maier et al., 1998; Lynch et al., 2013) and integrated with heart rate monitors (Weisenberger et al., 1996) to study exposure-response relationships and determine whether aircraft induce physiological impacts, even if a caribou appears to tolerate overflights (Murphy and Curatolo, 1987). Wildlife may experience physiological stress without exhibiting an observable change in behavior (Ditmer et al., 2015).

I have only begun to study how one human-human interaction (aircraft-harvester) relates to human-wildlife interactions (harvester-caribou). Future efforts simultaneously tracking spatial and temporal characteristics of harvester, caribou, and aircraft movement may provide insight into the causal relationships among these components of Arctic social-ecological systems. Understanding how aircraft affect caribou populations and traditional harvest practices will require a coordinated multidisciplinary approach that effectively engages all relevant stakeholders throughout the research process.

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